AD NUMBER

AD912659

NEW LIMITATION CHANGE

TO

Approved for public release, distribution unlimited

FROM

Distribution authorized to U.S. Gov't. agencies only; Test and Evaluation; Dec 1972. Other requests shall be referred to the Air Force Armament Laboratory, Attn: DLDG, Eglin AFB, FL 32542.

AUTHORITY

AFATL ltr, 6 Feb 1976

AD912659

AFATL-TR-72-232

RESEARCH AND DEVELOPMENT ON COEXTRUSION OF BIMETALLIC .220 SWIFT AND 25mm GUN BARRELS

BATTELLE-NORTHWEST DIVISION
BATTELLE MEMORIAL INSTITUTE

TECHNICAL REPORT AFATL-TR-72-232
DECEMBER 1972

AIR FORCE ARMAMENT LABORATORY

AIR FORCE SYSTEMS COMMAND • UNITED STATES AIR FORCE

EGLIN AIR FORCE BASE, FLORIDA

Research And Development On Coextrusion Of Bimetallic .220 Swift And 25mm Gun Barrels

Philip A. Ard

Distribution limited to U. S. Government agencies only; this report documents test and evaluation; distribution limitation applied December 1972. Other requests for this document must be referred to the Air Force Armament Laboratory (DLDG), Eglin Air Force Base, Florida 32542.

FOREWORD

This report was prepared by Battelle-Northwest (a division of Battelle Memorial Institute) Richland, Washington, under Contract Number F08635-71-C-0013 with the Air Force Armament Laboratory, Eglin Air Force Base, Florida. This report covers work done from July 1970 through October 1972. Mr. Ralph Blair and Mr. David Uhrig (DLDG) were the program managers for the Armament Laboratory. Mr. P. A. Ard, Research Engineer, was the principal investigator and Mr. R. S. Kemper, Manager, Materials Development Section, was the program manager.

This technical report has been reviewed and is approved.

DALE M. DAVIS
Director, Guns and Rockets Division

ABSTRACT

This was a research and development program on lined gun barrels directed toward selecting desirable barrel and liner material combinations which will increase the life of barrels in rapid fire gun systems and developing the fabrication processes for producing these barrels with a metallurgically bonded liner. Coextrusion was used as the method for producing the lined barrel stock. The program was divided into two parts with the first part directed toward producing lined .220 Swift barrels of selected material combinations for testing in the M-60 gun. The second part was directed toward producing a test quantity of 25mm barrels for testing in the GAU-7/A Gun System using the best material combinations and the fabrication techniques developed in the first part. Coextrusion was used as the method for producing the lined barrel stock. A-286 steel was selected as the barrel material, and TZM, Mo-0.5Ti, L605, Ta-10W, and T-222 were selected as the liner materials for the barrels. All the liners coextruded with the barrel steel satisfactorily over a small mandrel except T-222. The four successfully coextruded combinations were fabricated into .220 Swift barrels with swaging being used to rifle the barrels. The A-286 steel with an L605 liner was selected as the most promising combination for the 25mm barrels. The lined barrel blanks were produced by coextrusion on a 3850-ton press using a mandrel. The coextruded blanks were fabricated into GAU-7/A barrels by Philco-Ford Corporation.

Distribution limited to U. S. Government agencies only; this report documents test and evaluation; distribution limitation applied December 1972. Other requests for this document must be referred to the Air Force Armament Laboratory (DLDG), Eglin Air Force Base, Florida 32542.

(The reverse of this page is blank)

TABLE OF CONTENTS

TABLE OF CONTENTS (Concluded)

LIST OF FIGURES

LIST OF FIGURES (Concluded)

LIST OF TABLES

(The reverse of this page is blank)

SECTION I

INTRODUCTION

The Air Force is faced with the challenge of producing a rapid fire aircraft gun system which can fire large projectiles at high velocities and thus increase the probability of inflicting a kill on a fast moving air target. The high firing rates and the increased propellant loads produce gun barrel erosion to the extent that serious limitations are imposed on the gun systems. Materials evaluations in gun barrel tests have shown that improved erosion and wear resistance can be achieved heat resisting alloys and high melting point refractory 'loys are as barrel liners. Due to their high density, high cost oor duct y, poor formability, and difficult machining characteristi these oys are generally not practical for the major portion of the rrel b may be considered as a barrel liner. The rest of the barrel may nen be de of lower cost, more easily fabricated materials which have the desired elevated temperature strengths and ductility to perform satisfactorily under the severe stresses imposed during firing.

The purpose of this program was first to develop fabrication techniques and produce several .220 Swift barrels lined with five different materials for test firing on the M-60 weapon. This test simulates conditions experienced in the larger caliber gun system with a small caliber weapon. The technology developed for producing the .220 Swift lined barrels and the most promising material combination will be utilized to fabricate a small quantity of 25mm lined barrels for testing in the aircraft gun system.

High temperature, heat resistant A-286 steel was selected as the barrel material to be used in both the .220 Swift and the 25mm barrels. The molybdenum alloys TZM and Mo-0.5Ti, the tantalum alloys T-222 and Ta-10W, and the cobalt alloy L605 were selected as liner materials for the .220 Swift barrels. The alloy L605 was selected as the liner in the 25mm test barrels. The barrel liners were metallurgically bonded to the barrel material by coextrusion. The rifling in the .220 Swift barrels was produced by swaging; however, the gain twist rifling in the 25mm barrels was produced by machining.

SECTION II

SUMMARY

.220 SWIFT BARREL PROGRAM

Duplex billets of A-286 steel with TZM, Mo-05Ti, L605, Ta-10W alloy liners were successfully coextruded over a mandrel into lined, small bore gun barrel stock. From these coextrusions twelve .220 Swift barrels were fabricated for testing on the M-60 gun. Three barrels each with TZM, Mo-0.5Ti, L605, and Ta-10W liners were supplied for test firing and evaluation. An attempt to coextrude T-222 alloy lined A-286 barrel stock was not successful as the T-222 would not coextrude uniformily with the A-286 and instead extruded in lumps. An attempt to coextrude the T-222 with the higher strength CG-27 steel showed little improvement.

All the lined .220 Swift barrels produced in this program were rifled by swaging. The coextruded stock was prepared for rifling by chemically removing the extrusion sleeve material from the bore and honing the bore to the desired finish and size for swage rifling. The rifling step was performed on a 4-die swage using a modified swaging technique which prevented locking the short carbide rifling mandrels in the workpiece. All barrels were preheated and warm swage rifled to prevent cracking the liners.

25MM BARREL PROGRAM

Three duplex 25mm barrels were produced from coextruded barrel stock for testing in the GAU-7/A gun program. These barrels were A-286 with an L605 liner. The coextrusion techniques were basically the same as those used in the .220 Swift barrel program. The barrel stock was extruded from 8-inch-diameter billets on a 3850-ton accumulator press. The four billets extruded in Phase I of this program showed that it was feasible to produce lined barrel stock for this size of gun by coextrusion. The necessary changes in the billet design and extrusion conditions were made for Phase II, and four billets were successfully extruded. Three of these were machined into GAU-7/A barrels.

The barrel blanks were prepared for rifling by chemically removing the extrusion sleeve material, age hardening, and honing the ID to the required gun bore size and finish. The gain twist rifling in this barrel was produced by machining as this type of rifling cannot be formed by swaging over a mandrel as can constant twist rifling. The L605 liner was found to be readily machinable during rifling, allowing the use of the standard GAU-7/A machining technique.

SECTION III

BARREL AND LINER MATERIALS

BARREL MATERIAL

The heat resistant A-286 steel was selected for evaluation as a high temperature gun barrel material in this program. A barrel material should have good notch toughness and reasonable yield strength up to at least 1500°F to be an acceptable gun barrel material. The A-286 steel is austenitic under all conditions of heat treatment and has good continuous atmospheric corrosion resistance to 1300°F with good intermittent oxidation resistance to 1500°F. Optimum properties are obtained by a solution heat treatment and an aging treatment. The material is readily forgeable but has more resistance to deformation than the standard 300-series stainless steels.

Following are some typical values of A-286 steel after solution heating to 1800°F with an oil quench and aging at 1325°F for 16 hours.

A-286 (Iron Base - 15 Cr - 26 Ni - 1.3 Mo - 2.1 Ti - 0.3V)

Tensile Properties

Test Temperature, °F	Yield Strength 0.2% Offset, psi	Tensile Strength, psi	Elongation, %
70	93,500	143,500	24.0
1000	90,500	132,000	18.8
1200	86,000	103,000	13.0
1400	54,000	64,000	18.5

Hot Hardness

Test Temperature, °F	Rockwell Hardness
70	26.0 RHC
800	97.0 RHB
1000	95.5 RHB
1200	92.5 RHB

Impact Strength, Charpy V-Notch

Test Temperature, °F	ft-lb
-100	68.0
70	64.0
1000	45.5
1500	50.0

The A-286 material for the .220 Swift barrels was purchased to Aerospace Material Specification (AMS) 5737D. The material for the 25mm barrels was purchased to Aerospace Material Specification 5736E. Copies of the material certifications are shown in Appendices II and V.

LINER MATERIALS

The materials selected for evaluation as liners in the .220 Swift barrel tests were two molybdenum alloys TZM and Mo-0.5Ti, two tantalum alloys T-222 and Ta-10W, and one cobalt alloy L605. The L605 alloy was selected as the liner for the 25mm barrels. All alloys have good high temperature properties which are desirable for barrel liners.

Following are some typical mechanical properties for these alloys:

TZM (Molybdenum Base - 0.5 Ti - 0.08 Zr)

Condition: Rolled or Forged at 2200°F and Stress Relieved

Short-Time Tensile Properties

Test Temperature, °F	Yield Strength 0.1% Offset, psi	Tensile Strength, psi	Elongation, %
R.T.	102.4	119,600	29
1800	74.9	77,300	15
2000	64.3	73,100	17
2400	33.3	53,500	29

Hot Hardness

Temperature, °F	Diamond Pyramid Hardness
R.T.	220
1800	200
2000	180
2400	130

Molybdenum Base - 0.5 Ti

Condition 1: Rolled and Stress Relieved at 1800°F

Short-Time Tensile Properties

Test Temperature, °F	Yield Strength 0.1% Offset, psi	Tensile Strength, psi	Elongation, %
R.T.	99,100	132,100	31
750	89,000	110,000	-18
1200	84,000	100,500	17
1600	76,500	88,300	15

Condition 2: Forged or Rolled and Stress Relieved at 2100°F

Test Temperature, °F	R.T.
Yield Strength 0.2% Offset, psi	94.7
Tensile Strength, psi	112.1
Elongation, %	10
Diamond Pyramid Hardness	262

T-222 (Tantalum Base - 10 W - 2.5 HF - 0.012 C)

Condition: Hot Fabricated, Rolled, and Recrystallized

Short-Time Tensile Properties

Test Temperature, °F	Yield Strength 0.2% Offset, psi	Tensile Strength, psi	Elongation, %
R.T.	105.0	110.0	25
400	78.8	86.0	28
2000	40.8	77.6	18
2200	38.4	67.3	17
2400	37.8	53.4	20

Hardness at Room Temperature

238 - 280 Diamond Pyramid Hardness

Tantalum Base - 10 W

Short-Time Tensile Properties

Test Temperature, °F	Yield Strength 0.2% Offset, psi	Tensile Strength, psi	Elongation, %	Condition
R.T.	74,300	89,400	40.0	Recrystallized
R.T.	115,000	133,000	33.0	Stress Relieved, 2190°F
1500	95,000	103,000	12.0	As-Rolled Sheet
2200		41,000	12.0	Recrystallized
2500	19,000	20,000	20.0	As-Rolled Sheet

Impact Strength, Charpy Keyhole

Test Temperature, °F	ft-lb
0	100
400	105
800	140

L605 (Cobalt Base - 20 Cr - 10 Ni - 15 W - 1.5 Mn - 0.10 C)

Condition: Solution Annealed at 2200°F
and Rapid Cooled

Short-Time Tensile Properties

Test Temperature, °F	Yield Strength 0.2% Offset, psi	Tensile Strength, psi	Elongation, %
R.T.	85,800	160,700	47.0
1000	53,900	130,600	40.0
1400	49,000	73,000	12.0
1600	37,000	40,000	25.0
1800	27,500	29,200	37.0

Impact Strength

Test Temperature, °F	ft-lb	Type of Test
-58	114	Izod-notched
R.T.	120	Izod-nothced
1000	198	Charpy-V notch
1400	145	Charpy-V notch
1600	120	Charpy-V notch
1800	105	Charpy-V notch

Hot Hardness

Test Temperature, °F	Rockwell Hardness
R.T.	21 RHC
800	79 RHB
1000	77 RHB
1200	76 RHB

The molybdenum alloy materials were both purchased to Aerospace Material Specifications, the TZM alloy was purchased to AMS 7819, and the Mo-0.5Ti alloy to AMS 7813. Both the TZM and Mo-0.5Ti materials were recrystallized prior to machining into billet components. The TZM alloy was recrystallized at 2800°F, and the Mo-0.5Ti alloy was recrystallized at 2600°F. The Ta-10W alloy was purchased fully recrystallized to Aerospace Material Specification 7848, and the T-222 alloy was purchased in the recrystallized condition to requirements specified in the purchase order. The L605 material was purchased in the solution heat-treated condition to Aerospace Material Specification 5759D. Copies of all material certifications are included in Appendix II and V.

SECTION IV

.220 SWIFT BARREL FABRICATION

FABRICATION APPROACH

Each fabrication step used in producing the .220 Swift barrels is given in the proper sequence in Table I. The lined barrel stock was produced by coextrusion which provides a full length uniform liner that is metallurgically bonded to the barrel steel during the hot extrusion step. All the barrels were swage rifled as some of the liner materials are very difficult to machine, particularly the molybdenum and tantalum alloys. Barrel chambering and OD contouring were by conventional machining methods.

The barrel fabrication process is divided into seven areas for this discussion: (1) billet fabrication, (2) coextrusion of barrel stock, (3) blank preparation, (4) rifling, (5) heat treatment, (6) final machining and inspection, and (7) socket and cylinder assembly.

Billet Fabrication

The design of the composite coextrusion billets used for coextrusion of the lined barrel stock is illustrated in drawing R-1925, which is Figure I-1 in Appendix I. An assembled billet is shown in Figure 1. The center sleeve and both end caps were fabricated from 304 stainless steel to prevent excessive oxidation of these parts during billet preheat. The center billet sleeve on the initial billets was 0.040 inch thick, but in billets T22, TW2, TW3, L53, L54, TM2, TM3, MT2, and MT3 the center sleeve wall was increased to 0.058 inch to reduce the chilling effect of the relatively cold mandrel and mandrel sleeve.

The machined billet components were cleaned prior to assembly by first degreasing in trichlorethylene followed by deionized water and alcohol rinses and an air dry. Prior to rinsing the outer diameter surface of the liner was abrasive dry-blasted using glass beads to remove surface oxides. Initially, the billets were assembled and vacuum sealed by electron beam welding. However, billets T21, TW1, MT1, and L52 were found to be leakers producing a poor bond between the liners and the barrel steel in the extrusion. The leaks were found to be from small cracks generated in the A-286 steel during electron beam welding. Subsequent welds were made by TIG welding using a Hastalloy W filler material. The inside of the billet was flooded with argon during welding and then evacuated and helium leak checked, using the evacuation tube shown in drawing R-1925, Figure I-1 in Appendix I. If the welds checked helium tight, the evacuation tube was pinched off and sealed.

TABLE I. PROCESSING STEPS AND CONDITIONS FOR FABRICATING .22 CALIBER LINED GUN BARRELS

Process Step	Process Conditions or Requirements
1. Machine billet components	Per dimensions shown on drawing R-1925
2. Clean billet components	Degrease, abrasive dry blast and rinse
3. Assemble billet	Per drawing R-1925
4. Extrude	2050°F to 2150°F preheat (see Table II)
5. Straighten extrusion	Sutton roll straightener
6. Cut into barrel blanks	Water cooled abrasive wheel
7. Chemically remove billet and mandrel sleeve	Hot 10% solution of H_2SO_4 acid
8. Hone blank bore	0.230 to 0.238 inch ID and a 32 micro-inch finish
9. Partial aging for swaging	1325°F for 1 1/2 hours in vacuum (barrels TM2-1, TM3-2, TM3-3, and TW2-3 only)
10. Swage rifling	12% reduction at 900°F
11. Straighten barrels	Straight within 0.002 inch per foot of length
12. Inspect rifling	Air gage check
13. Age harden A-286 steel	1325°F for 16 hours in vacuum
14. Chamber barrels	Per drawing R-1492, reamer per drawing R-1927
15. Rough machine OD contour	Within 0.040 inch
16. Inspect bore straightness and straighten if required	Straightness checked visually on bore
17. Final machine barrels	Per drawing R-1492
18. Inspect barrels	To drawing R-1492
19. Install sockets and gas cylinders	Per drawing R-1798
20. Final inspect	To drawing R-1798

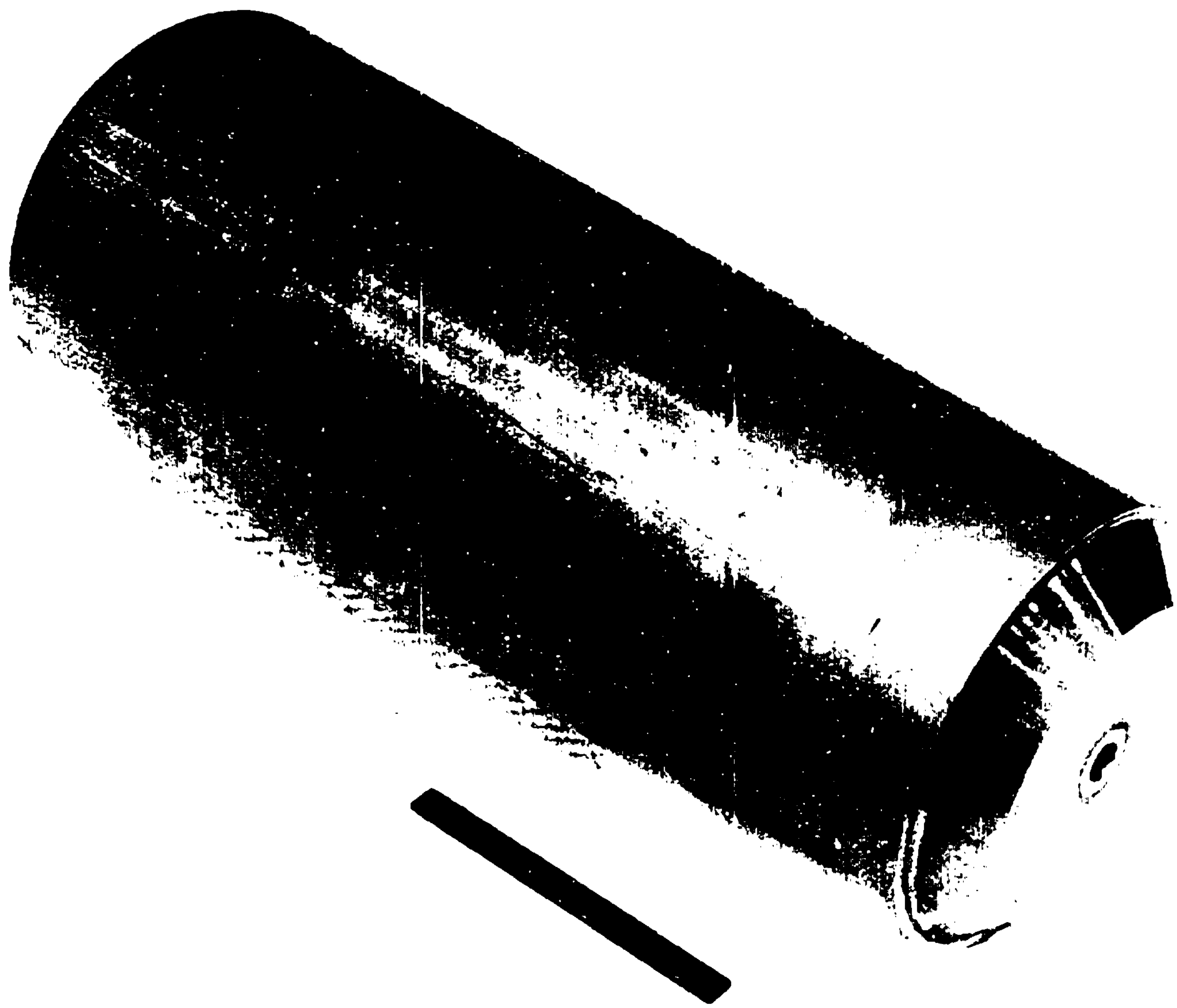


Figure 1. Billet from Which the .22 Caliber Duplex Barrel Stock was Extruded

Coextrusion of Barrel Stock

The billets for the .220 Swift barrels were extruded on a 1250-ton horizontal Loewy-Hydropress (water accumulator-actuated) shown in Figure 2. The press has a 59-inch stroke, a maximum ram closing speed of 840 inches/minute, and a maximum pressing speed of 480 inches/minute. The 4-inch resistance heated billet container was operated at 750°F.

The conical entry extrusion dies were fabricated from H-12 tool steel, and the cone and the throat surfaces were coated with zirconia by the Rokide®* process. The extrusion mandrels were made from AISI type T-1 tool steel hardened to R_c 57-60. The mandrel has a 0.010-inch taper to help reduce the extrusion drag on the small mandrels. The die, mandrel, and the 1010 steel mandrel heat barrier sleeve are shown in drawing R-1924, Figure I-2, in Appendix I. The die, mandrel, and mandrel sleeve are shown in Figure 3. The mandrel sleeve which extrudes with the billet has the purpose of slowing the rate of heat flow from the billet into the mandrel during extrusion, allowing sufficient time to complete the extrusion before the mandrel overheats. The mandrel sleeve is placed over the mandrel with a heavy lubricant layer between the mandrel and sleeve which also helps to reduce the rate of heat flow as well as lubricate the mandrel.

The billets were placed in closed stainless steel cans and preheated for 2 1/2 to 3 hours to the temperatures indicated in Table II. The preheating was in a resistance-heated air atmosphere furnace, and the stainless cans helped to reduce billet oxidation. The extrusion die was preheated to 750°F prior to the extrusion, but neither the mandrel nor the mild steel mandrel sleeve was preheated. After removal from the furnace, the billet is quickly loaded into the extrusion container along with a graphite block machined to accommodate the mandrel head. The purpose of the graphite block behind the billet is to clear the billet from the die and mandrel at the end of the extrusion stroke. The mandrel, together with the heat barrier sleeve, is inserted through the graphite block into the billet after the billet and graphite block are loaded into the press to lessen mandrel exposure time to the hot billet.

The die and extrusion container was lubricated with a suspension of graphite and oil followed by a coating of Phosphathern RN®* prior to each extrusion. No lubricant was applied to the billets. The lubricant between the mandrels and the heat barrier sleeve consisted of graphite and copper fines.

The conditions and the results of each extrusion are given in Table II; a typical coextrusion is shown in Figure 4 along with a cut section of the

®* A patented coating process by Norton Company.

** A hot steel extrusion lubricant marketed by the Alpha-Molykote Corporation.

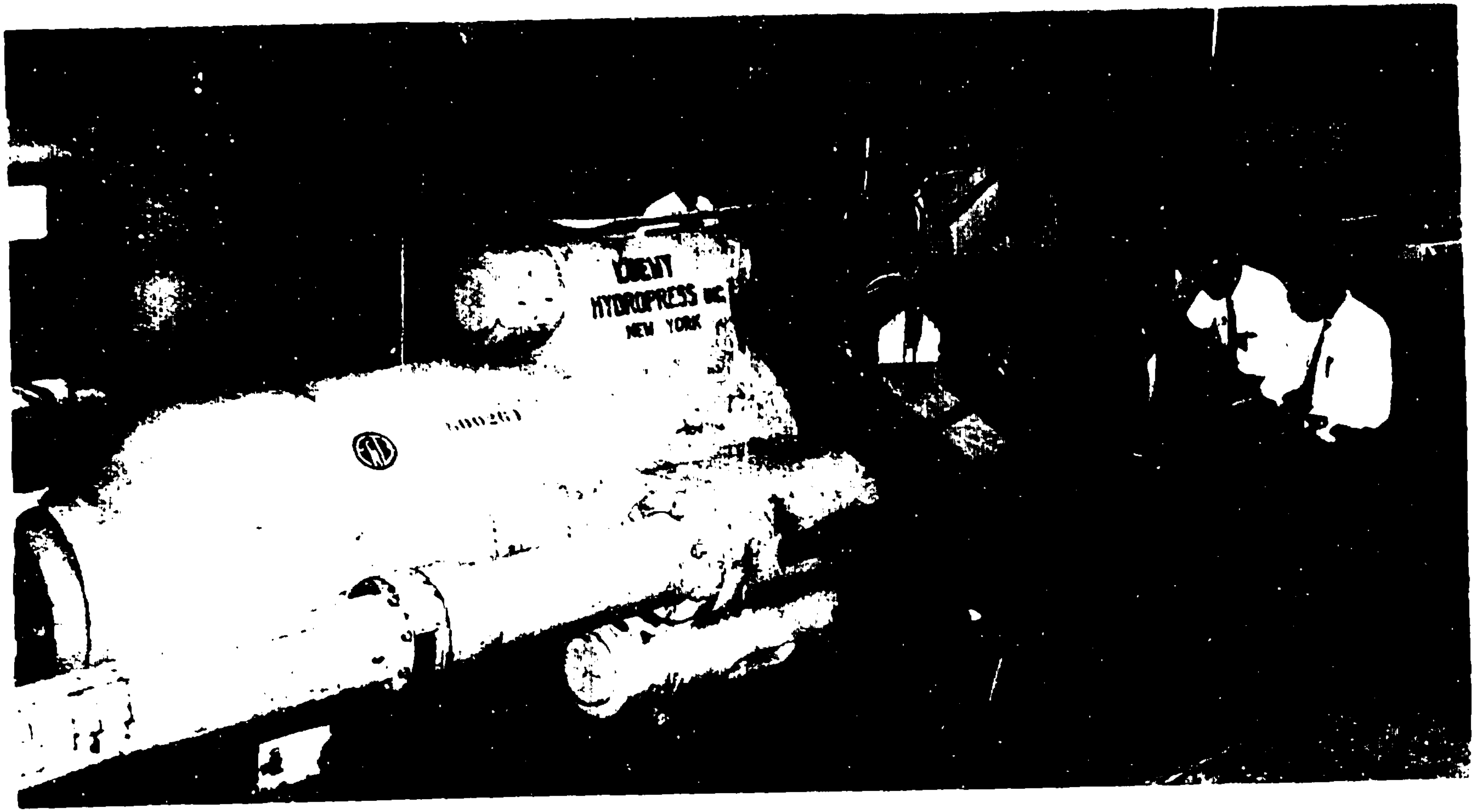


Figure 2. 1250-Ton Loewy Extrusion Press Used to Extrude the Billets for the .220 Swift Barrels

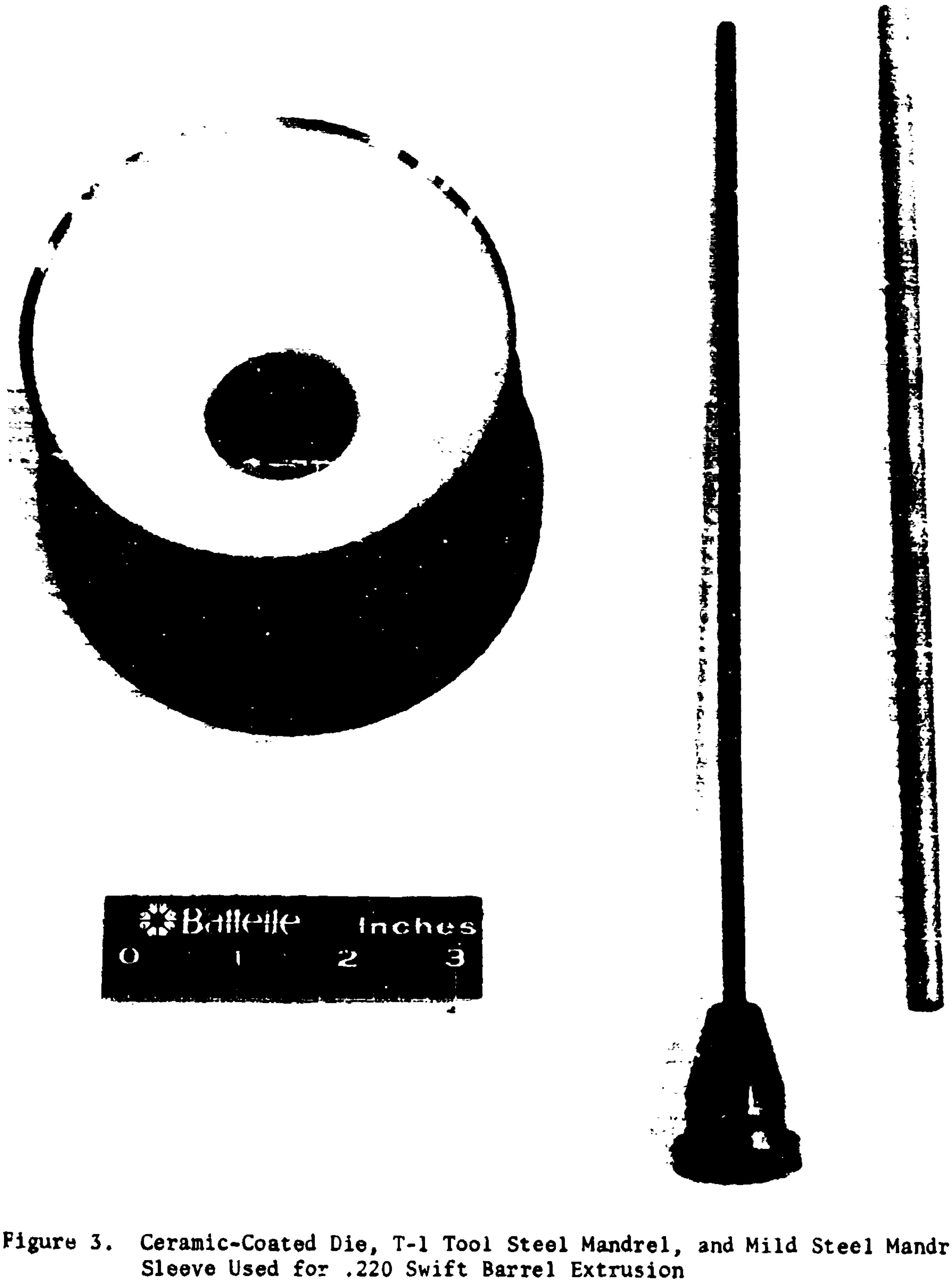


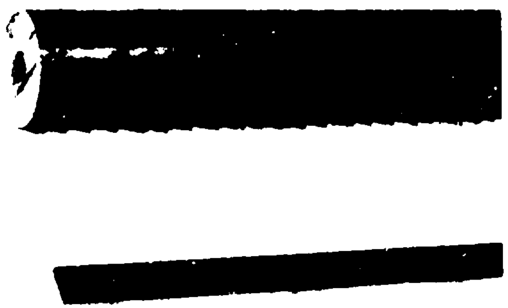
Figure 3. Ceramic-Coated Die, T-1 Tool Steel Mandrel, and Mild Steel Mandrel Sleeve Used for .220 Swift Barrel Extrusion

TABLE II. CONDITIONS AND RESULTS OF LINED .220 SWIFT BARREL EXTRUSIONS

Billet Number	Billet Mat'l	Liner Mat'l	Billet Preheat, °F	Extrusion Diameter, in.	Press Ram Speed, in./min	Extrusion Force, tons		Comments
						Start	Run	
TM1	A-286	TZM	2050	1.330	350	855	830	Extrusion, OK
TM2	A-286	TZM	2100	1.322	325	794	780	Extrusion, OK
TM3	A-286	TZM	2100	1.320	330	790	790	Extrusion, OK
MT1	A-286	Mo-0.5Ti	2050	1.330	340	850	825	Poor bond billet leaked
MT2	A-286	Mo-0.5Ti	2100	1.320	345	850	794	Extrusion, OK
MT3	A-286	Mo-0.5Ti	2100	1.320	350	775	755	Extrusion, OK
L51	A-286	L605	2050	1.350	350	820	790	Extrusion, die eroded
L52	A-286	L605	2050	1.330	340	875	860	Poor bond billet leaked
L53	A-286	L605	2150	1.327	- No Extrusion Chart -			Extrusion, OK
L54	A-286	L605	2150	1.325	390	750	730	Extrusion, OK
TW1	A-286	Ta-10W	2050	1.332	340	900	850	Poor bond billet leaked
TW2	A-286	Ta-10W	2100	1.320	340	770	755	Extrusion, OK
TW3	A-286	Ta-10W	2100	1.325	330	740	760	Extrusion, OK
T21	A-286	T-222	2050	1.340	360	875	850	Liner extruded in lumps
T22	CG-27	T-222	2050	1.335	325	- No Force Chart -		Liner extruded in lumps

Conditions:
1. Press - 1250-Ton Loewy Hydropress
2. Tooling Temperature 750°F
3. Lubricant: Die - Oil Dag and Phosphathern RN
   Mandrel - Oil Dag and Fel Pro
4. Billet Outer Diameter - 4 inches
5. Extrusion Reduction - 8.92 (Based on billet size)

Duplex Barrel Coextrusion



Extruded Barrel Section

Figure 4. A Coextrusion of Lined .22 Caliber Barrel Stock (Top), As-Extruded, and a Close-Up View (Bottom) Showing a Transverse Cut Through the Coextrusion Revealing the Small Extruded Hole

extrusion showing the small extruded bore. Radiographs of an A-286 steel extrusion with each of the five types of liners are shown in Figures 5, 6, and 7. As is evident in Figure 7, the T-222 liner would not coextrude with the A-286 steel but instead extruded in lumps within the steel.

Blank Preparation

The coextruded stock was cut into barrel blank lengths, and the bores were prepared for swage rifling by first removing the mild steel mandrel sleeve and stainless steel billet center sleeve material and then honing the bore to a diameter between 0.230 to 0.238 inch with a 32-microinch finish. Two approaches were tried for preparing the blank bores for rifling. The initial approach consisted of counterboring the sleeve materials from the bores using a gun counterbore tool followed by a light honing operation to provide the desired finish. This approach proved to be unsatisfactory as the counterbore tool would not follow the extruded liner bore close enough to prevent leaving areas with sleeve materials on one side of the bore while excess liner materials were removed from the opposite side of the bore. Also, the Ta-10W liners could not be counterbored as the counterbore tool tended to seize to the material. The barrel liner ID was extruded about 0.010 inch under the desired diameter range to allow for boring and honing.

The second approach consisted of first acid milling the sleeve materials from the extruded barrel stock bores using a hot 10 percent sulfuric acid solution followed by honing the bore to the desired diameter and finish. The ID of the blank liners was extruded to a diameter of about 0.230 inch to allow material for clean-up during honing. This approach provided the most satisfactory barrels as it did not affect the uniformity of the liner, and all liner materials used could be prepared by this approach. The barrels supplied under this contract were all prepared by this approach.

The barrel blanks were centerless ground to an outside diameter of 1.310 inches for swage rifling. The condition of the barrel stock was as-extruded with no subsequent heat treatments prior to swaging except on blanks TM2-1, TM3-2, TM3-3, and TW2-3 (see Table III) which were partially aged in an attempt to better match the hardness of the barrel material to the liner material to provide a smoother rifling. The A-286 steel was about 85 to 100 R_B as-extruded and with a 1 1/2-hour 1325°F partial age the hardness was about 27 R_C. The hardness of the molybdenum alloy liners was about 270 DPH as-extruded, and the hardness of the L605 liner was about 22 R_C as-extruded.

Each barrel was welded to a steel handle so that the entire barrel length could be fed through the swage.

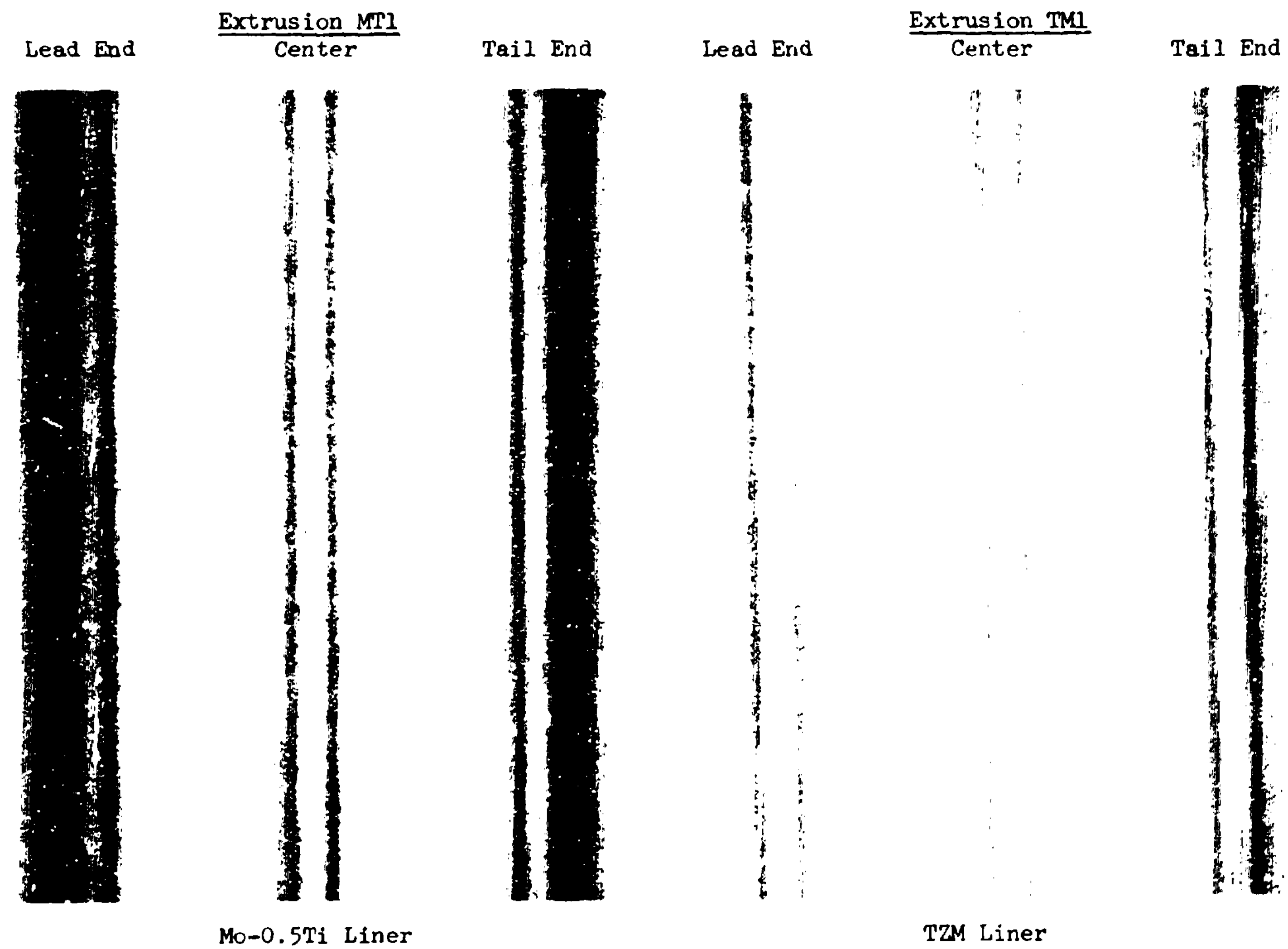


Figure 5. Radiographs Showing Sections of the Molybdenum Alloy Liners in A-286 Barrel Stock at the Lead End, Center, and Tail End of Extrusions MT1 and TM1. The Parallel Broad Dark Lines are the Liner Material.

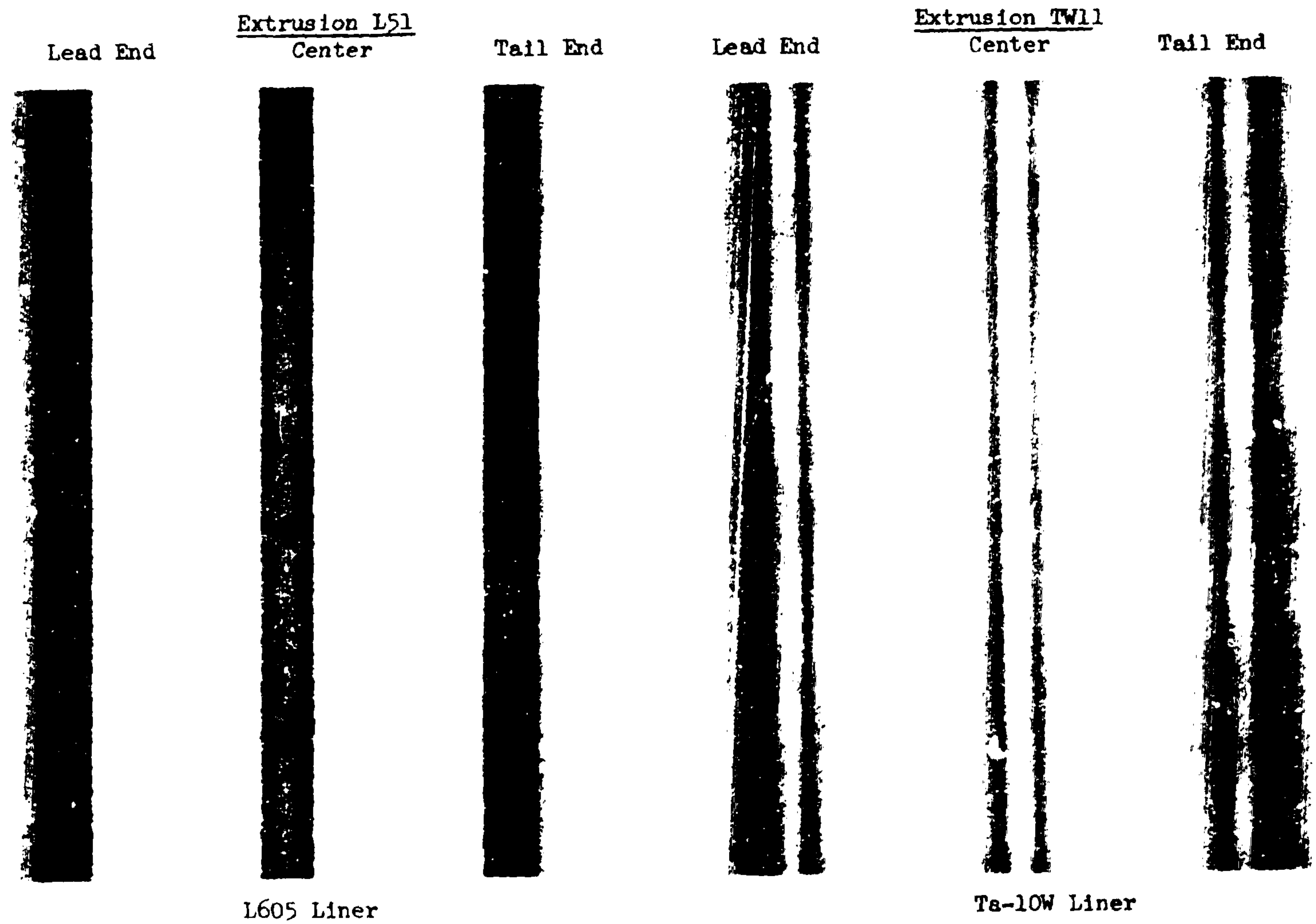
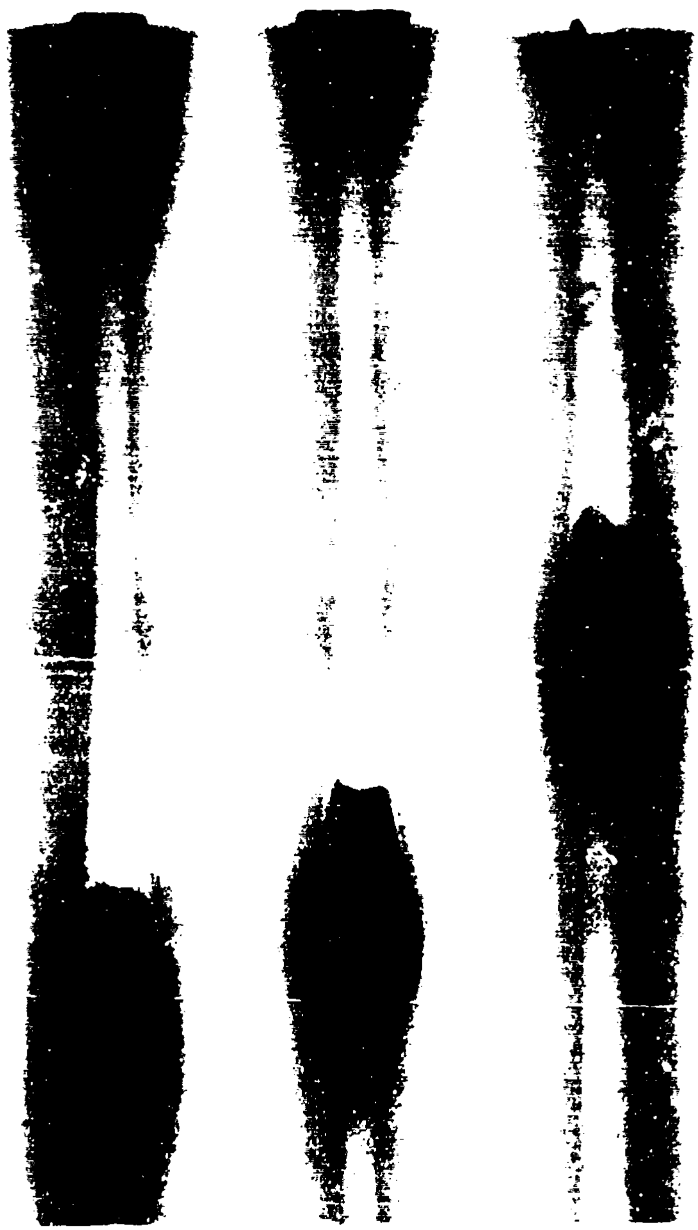


Figure 6. Radiographs Showing Sections of L605 and Ta-10W Alloy Liners in A-286 Barrel Stock at the Lead End, Center, and Tail of the Extrusions L51 and TW1. The Parallel Broad Dark Lines are the Liner Material.

Extrusion T21

Lead End Center Tail End



T-222 Liner

Figure 7. Radiographs Showing the Results of Coextruding T-222 Alloy with A-286 Steel. The Dark Areas are the T-222 Material.

Rifling

The lined barrel blanks were rifled by rotary swaging the barrels over a tungsten carbide mandrel. The mandrel location within the swage is fixed, and the barrel blank moves over the mandrel as it is rifled. A 5F 4-die Fenn rotary swage, shown in Figure 8, was used for the swaging operation. The swaging dies were made of H-13 tool steel and were the R-2 die set shown on drawing H-3-25648, Figure I-3, in Appendix I. The rifling mandrel shown in Figure 9 with a section of a rifled barrel was made of carboloy 55B. A drawing of the mandrel (drawing R-1493, Part 1, Figure I-4) is also shown in Appendix I.

All the barrel blanks were preheated to 900°F in a tube furnace prior to swaging to prevent cracking the molybdenum alloy and L605 liners. The Ta-10W alloy liner could be cold swaged without cracking, but a more uniform rifling was produced when the blanks were preheated to 900°F. To prevent the mandrel from locking in the blank during swaging, a light graphite lubricant was used and the swaging technique was altered to allow two opposing swaging dies to strike the barrel slightly ahead of the other two opposing dies. This was accomplished by using different shim thickness behind each pair of opposing dies.

As determined by metallography of specimens from the as-swaged barrels, the hot swaging operation appeared not to damage the bond between the barrel steel and the liner material. A swaging operation record of the barrel blanks supplied is given in Table III.

Heat Treating

Following the rifling step the lined A-286 steel barrels were checked for a straightness of 0.002 inch per foot of length and, if necessary, straightened to this requirement. After straightening, the A-286 steel was age hardened by holding the barrels at 1325°F in a vacuum for 16 hours. The vacuum was used to protect the refractory liners during the long time at temperature.

Samples of extruded A-286 steel barrels were solution heat treated to determine the effect on the bond and evaluate the need for a solution heat treatment following extrusion. The solution heat treatment consisted of heating to 1800°F for one hour followed by an oil quench. No detrimental effect on the bond was discernible, but the solution heat-treated barrels appeared not to have any advantage over the as-extruded barrels for swage rifling or in the properties of the barrel after aging. The most desirable condition would be to quench the barrels immediately after extrusion to prevent grain growth in the A-286. The A-286 steel barrels supplied in this contract were air cooled after extrusion with no subsequent solution heat treatment. The final barrel hardness after aging was in the range of 29 to 32 R_c.

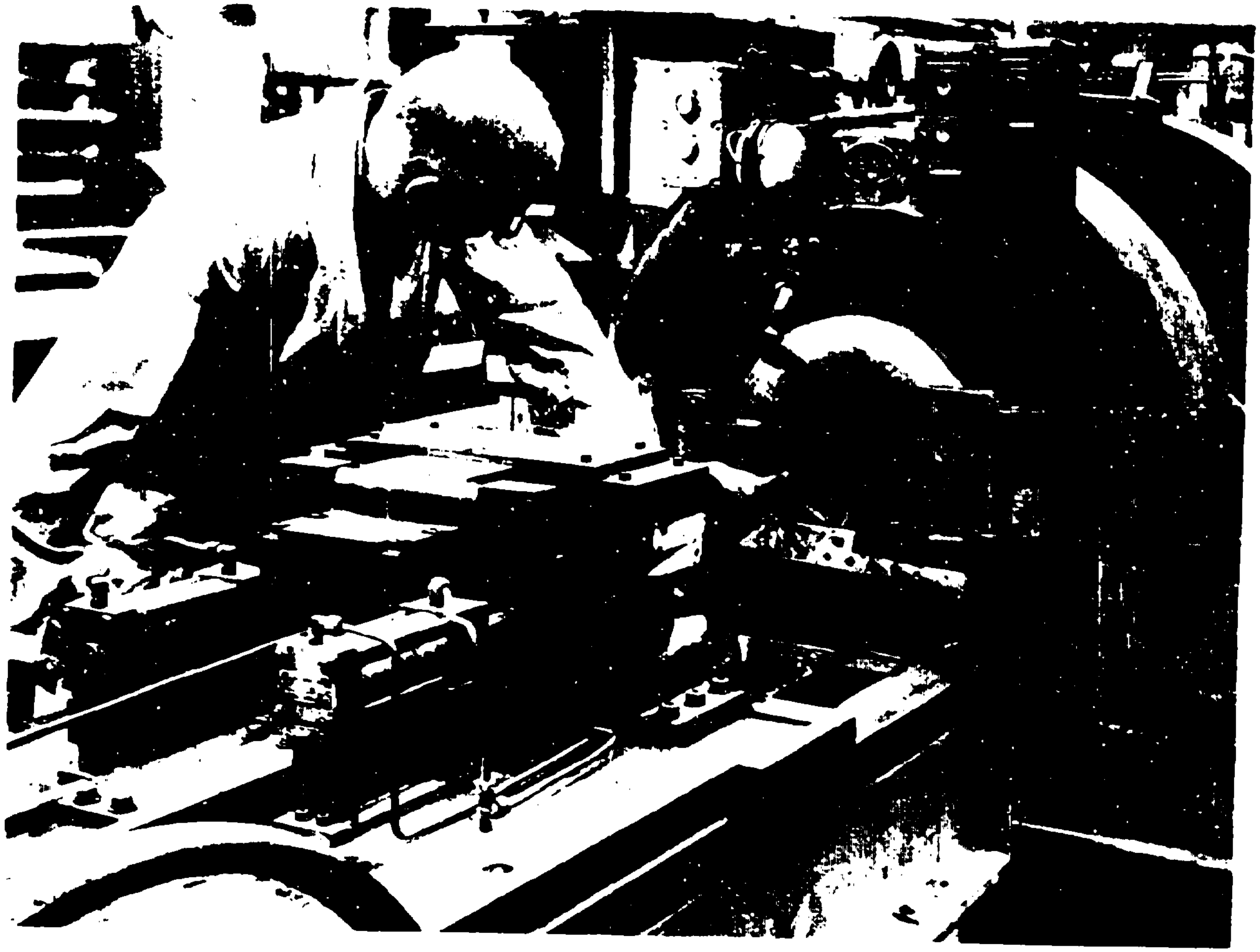


Figure 8. Rotary Swage Used to Rifle the Bores of the .220 Swift Duplex Barrel Blanks

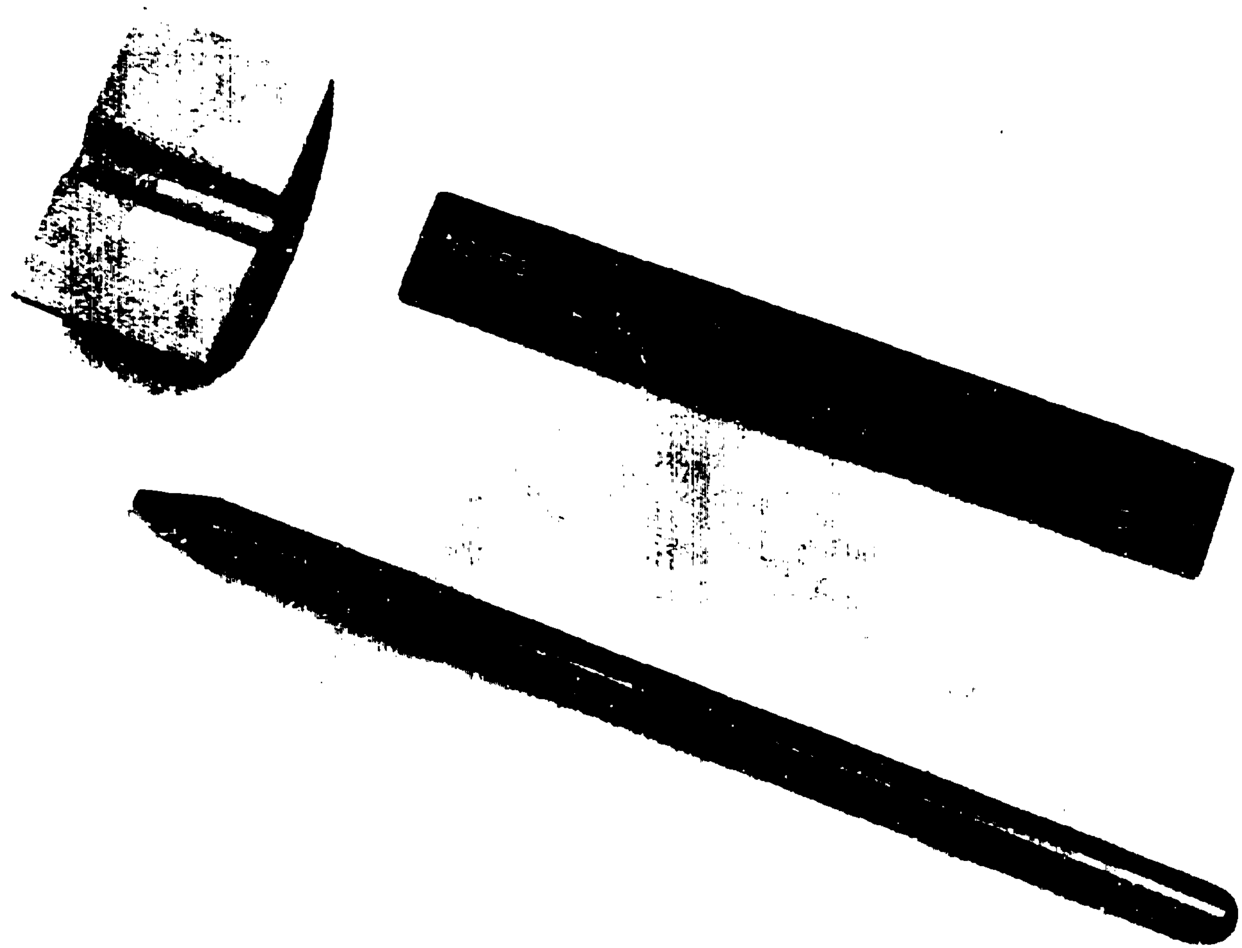


Figure 9. Longitudinal Section of a Swage Rifled Barrel and a View of the 6-Groove Carbide Rifling Mandrel Used in Rifling the .220 Swift Barrels

TABLE III. RIFLE SWAGING CONDITIONS AND RESULTS OF .22 CALIBER LINED BARREL RIFLING (AS-SWAGED)

Barrel Number	Blank Condition				Swage Data					Swaged Blank Condition					Comments
	OD, in.	ID, in.	Length, in.	OD Hardness	Die Size, in.	Shims 0°/90°	Rifling Mandrel Size, in.	Preheat, F	Feed Speed, in./min	OD, in.	Length, in.	OD Hardness	Groove, in.	Bore in.	
L53-1	1.312	0.235	24 7/8	68R_B	1.200	0.290/0.277	0.224	900	30	1.217	29	20R_c	0.2245	0.2193	
L54-2	1.313	0.238	25	92R_B	1.200	0.290/0.277	0.224	900	30	1.218	29 1/8	23R_c	0.2244	0.2195	
[illegible]	1.311	0.238	25	97R_B	1.200	0.290/0.277	0.224	900	30	1.218	29	22R_c	0.2244	0.2194	
TM2-1	1.312	0.235	25	27R_c	1.200	0.290/0.270	0.224	900	30	1.231	28 1/4	34R_c	0.2243	0.2193	Preaged blank
TM3-2	1.312	0.237	25	29R_c	1.200	0.290/0.272	0.224	900	30	1.230	28 3/8	35R_c	0.2240	0.2192	Preaged blank
TM3-3	1.310	0.237	25	30R_c	1.200	0.290/0.272	0.224	900	30	1.230	28 1/8	34R_c	0.2242	0.2193	Preaged blank
MT2-3	1.31[illegible]	0.234	25	90R_B	1.200	0.290/0.275	0.224	900	30	1.218	29	21R_c	0.2245	0.2193	
MT3-1	1.31[illegible]	0.236	25	93R_B	1.200	0.290/0.275	0.224	900	30	1.218	29	22R_c	0.2245	0.2193	
MT3-2	[illegible]	0.23[illegible]	25	90R_B	1.200	0.290/0.275	0.224	900	30	1.218	29	21R_c	0.2244	0.2192	
[illegible]	[illegible]	0.232	24 3/4	27R_c	1.200	0.290/0.272	0.224	900	30	1.230	28 1/4	34R_c	0.2245	0.2192	Preaged blank
TM3-2	1.312	0.235	25 1/8	95R_B	1.200	0.290/0.272	0.223	900	30	1.222	28 7/8	24R_c	0.2243	0.2192	
TM3-3	1.312	0.233	25 1/8	96R_B	1.200	0.290/0.275	0.224	900	30	1.218	29 1/8	22R_c	0.2247	0.2198	

Swage - Fenn 5F, 4-die

Final Machining and Inspection

The rifled barrel blanks were machined into .220 Swift barrels in accordance with drawing R-1492, Figure I-5 of Appendix I, using conventional machining techniques. The first step was chambering which was accomplished using a high speed steel roughing reamer followed by a carbide finishing reamer, drawing R-1927 (Figure I-6 of Appendix I). The carbide reamer would not satisfactorily cut the Ta-10W lined barrels tending to gall and seize. This was alleviated by using high speed reamers for the entire chambering step. The molybdenum and tantalum alloy under materials were very abrasive, requiring frequent resharpening of the reamers.

Following chambering the outer diameter contour of the barrels was then rough turned to near the finish dimensions and then bore checked for straightness. If necessary, the barrels were straightened before going on to finish machine the barrel. The finish machined .220 Swift barrel is shown in Figure 10.

The rifling in the barrels was checked for dimensional accuracy with an air gage following swaging and again during the final inspection. The bore and chamber were inspected with a borescope to determine the finish condition of the rifling and chamber. The finish chamber reamers were ground to provide the desired chamber form and dimensions and were checked with an optical comparator initially and after each sharpening to insure the shape and accuracy. The headspace was checked using a flush-pin gage which is shown in drawing R-1926, Figure I-7 of Appendix I. The barrel diameter outer contour and threads were inspected using conventional inspection tooling and thread gages. The final inspection records are given in Appendix III.

Socket and Cylinder Assembly

After inspection the barrels were assembled with the chamber sockets and gas cylinders supplied by the program sponsor. The assembly was in accordance with drawing R-1798, Figure I-8, in Appendix I. The 0.110-inch gas hole from the gas cylinder into the barrel bore was made by electrical discharge machining which left a clean burr-free hole into the bore. Three barrels with the sockets and gas cylinders installed are shown in Figure 11 along with a close-up of an installed chamber socket.

The results of the final inspection of the assemblies are also given in the inspection records in Appendix III.

Figure 10. Completed .220 Swift Gun Barrel Ready for Installation of the Socket and Gas Cylinder

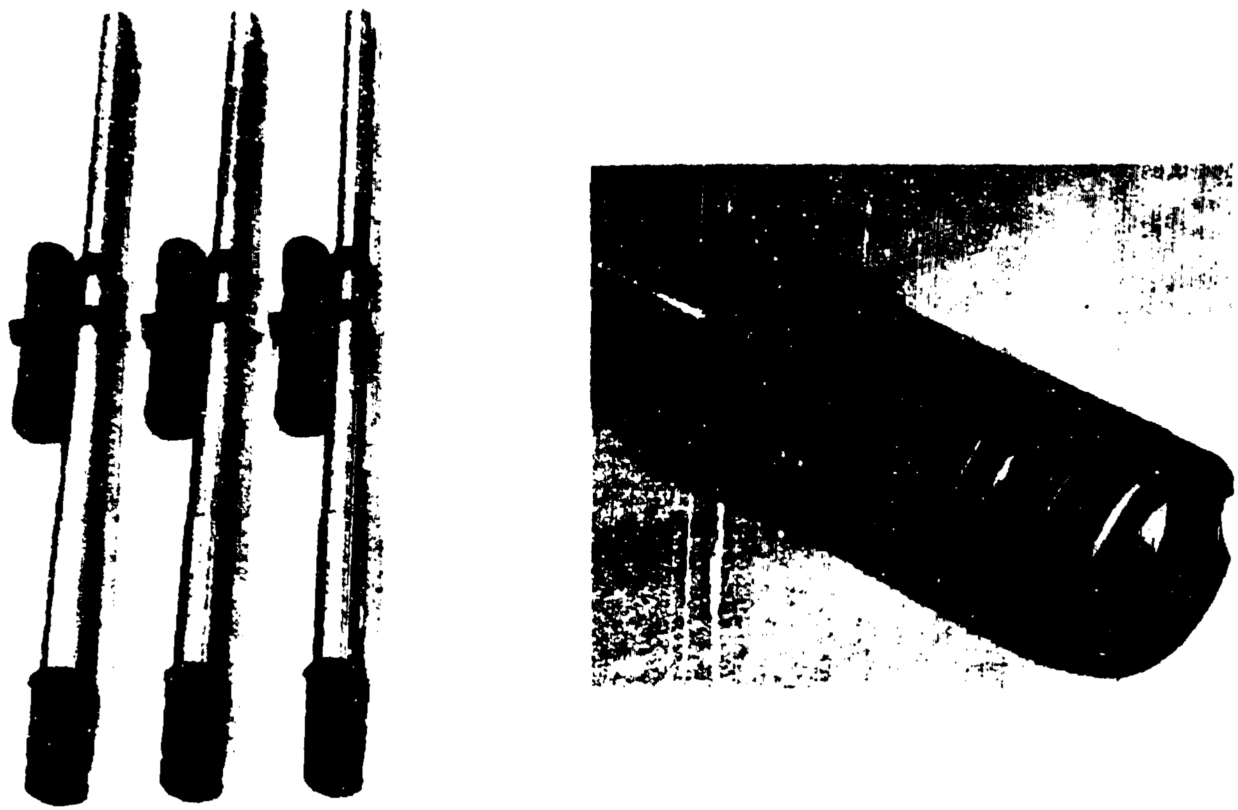


Figure 11. Three Completed .220 Swift Barrels with the Gas Cylinders and Sockets in Place Along with a Close-Up View of an Installed Socket

SECTION V

25MM BARREL FABRICATION

FABRICATION APPROACH

Table IV lists the process steps in sequence and the conditions which were imposed at each step. The lined barrel stock was produced by coextrusion which was accomplished on a large extrusion press operated by Reactive Metals, Inc., Astabula, Ohio. The coextruded barrel blanks were rifled and machined into 25mm GAU-7/A barrels by Philco-Ford Corporation, Newport Beach, California. A process sequence chart is shown in Figure 12 which depicts, in order, the major steps in fabricating the lined 25mm barrel.

The fabrication process will be divided into five steps for this discussion: (1) billet fabrication, (2) coextrusion of the barrel stock, (3) blank preparation, (4) rifling and final machining, and (5) inspection.

Billet Fabrication

The design of the duplex coextrusion billet used for the final four coextrusions is shown in drawing R-1838, Figure IV-1 in Appendix IV. The 8-inch assembled billet is shown in Figure 13. The billet center sleeve was 1010 steel, and both end caps were fabricated of 1020 steel. The billet center sleeve on the first four was 0.095-inch thick but was increased to 0.120-inch thick on the next four billets to help reduce chilling of the L605 liner by the relatively cold mandrel and mandrel sleeve. Both billet seal caps were made of 304 stainless steel and serve the purpose of sealing the billet interior. The flex seal cap on the tail end of the billet is designed to accommodate the difference in thermal expansion between the A-286 billet and the mild steel sleeve and thus prevents tearing the welds on the billet center sleeve during preheat. This flex seal was increased in diameter for the second group of billets to further reduce the stresses in the weld.

All components in the billets were cleaned prior to assembly by degreasing in trichlorethylene followed by a hot deionized water rinse. In addition, the A-286 steel billet and L605 liner were chemically bright etched followed by a rinse to insure the optimum surface cleanliness for bonding. The billets were assembled and TIG welded using Hatalloy W filler rod. The inside of the billets was flooded with argon while making the welds on the seal caps. These welds were then checked by evacuating the billet and helium leak checking. If the weld checked helium-tight, the evacuation tube was pinched off and sealed. The mild steel end caps were then welded to each end of the billet.

TABLE IV. PROCESSING STEPS AND CONDITIONS FOR FABRICATING 25MM LINED GUN BARRELS

Process Step	Process Conditions or Requirements
1. Machine billet components	Per dimensions shown on drawing R-1838
2. Clean billet components	Degrease and chemically clean
3. Assemble billet	Per drawing R-1838
4. Extrude	2040 to 2150°F preheat (See Table V.)
5. Straighten extrusion	100-ton gap press (within 0.003 in./ft on OD)
6. Cut into barrel blank lengths	Cut with an abrasive saw
7. Chemically remove billet and mandrel sleeve	10% solution of HNO_3 acid
8. Age harden A-286 steel	1325°F for 16 hours
9. Rough turn OD and check straightness	To ≈ 2-1/2 in. OD and straight to within 0.002 in./ft on bore
10. Hone blank ID	Hone to barrel bore dimension 0.984 + 0.002 inch.
11. Rifle bore	Machine rifle per Philco-Ford drawing 47408 (EM1 Gun)
12. Rough machine OD contour	Leave sufficient material for straightening
13. Check bore straightness and correct as required	Straight to within 0.002 in./ft on bore
14. Final machine barrels	Per Philco-Ford drawing 47408 (EM1 Gun)
15. Inspect barrels	All dimensions to Philco-Ford drawing 47408 (EM1 Gun)

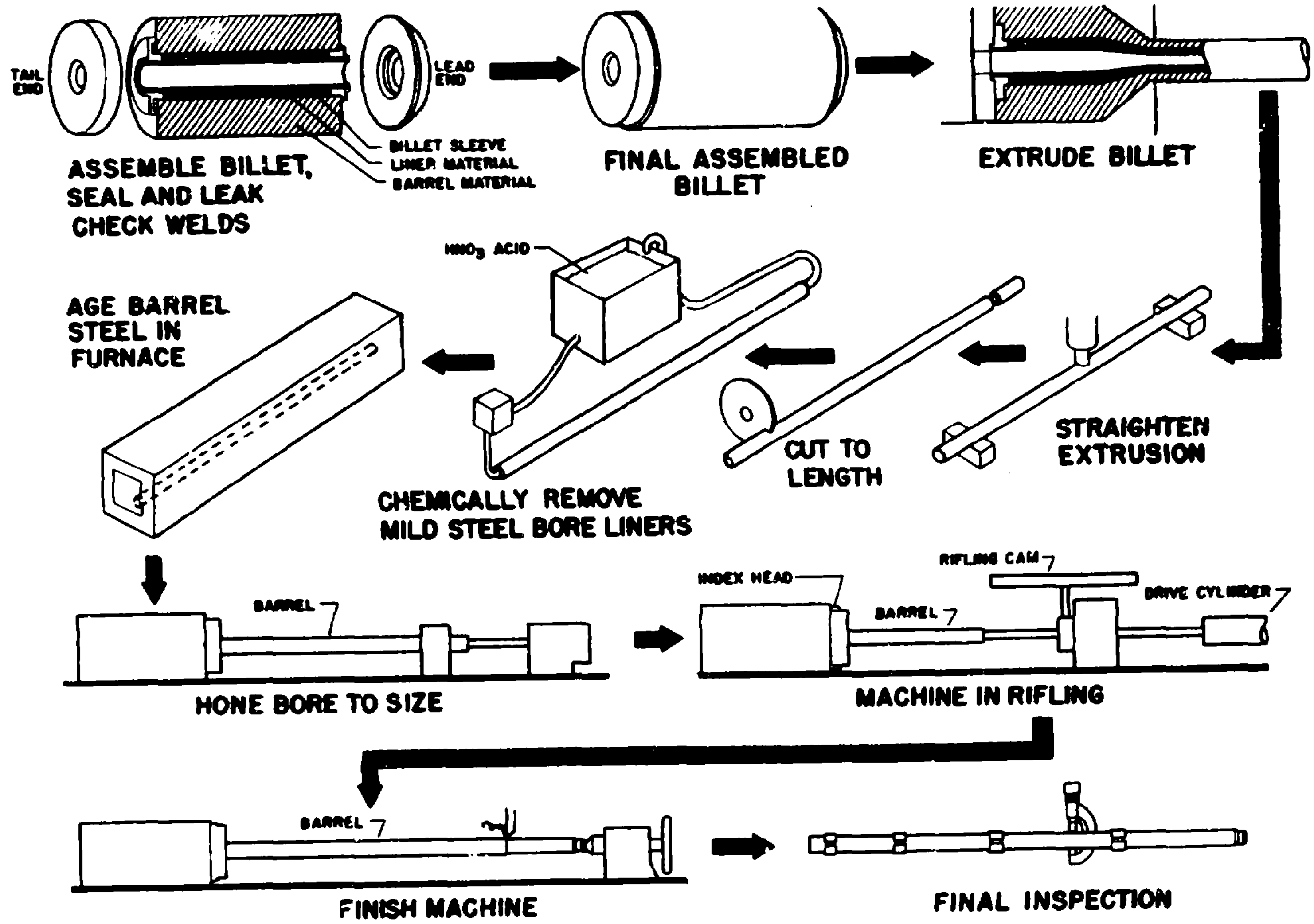


Figure 12. Process Sequence Chart Depicting Steps in 25mm Barrel Fabrication

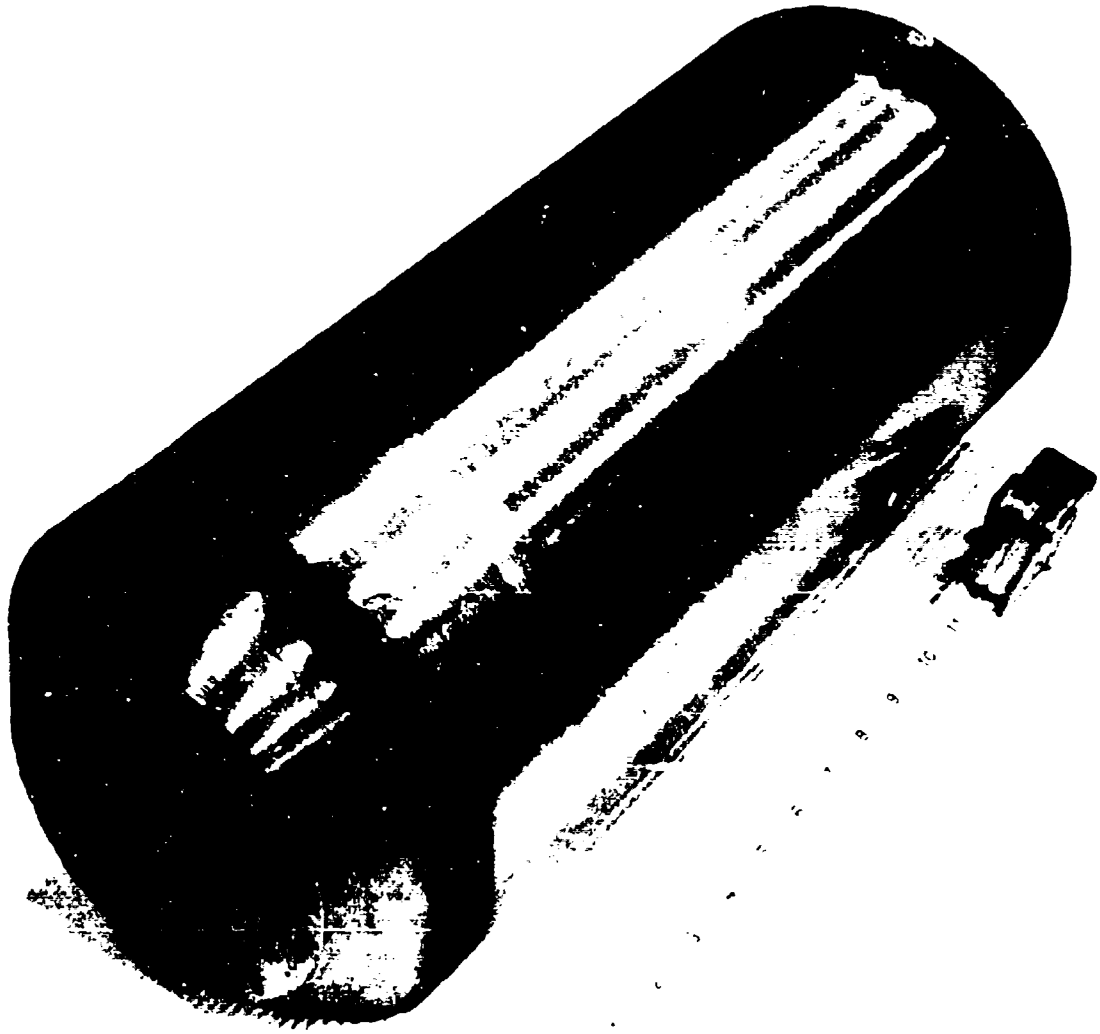


Figure 13. Eight-Inch-Diameter Billet for Which the 25mm Duplex Barrels Were Extruded

Coextrusion of Billets

The 8-inch-diameter billets were extruded on a 3850-ton horizontal Loewy press (accumulator actuated) operated by Reactive Metals, Inc., Ashtabula, Ohio. This press, which is shown in Figure 14, has a maximum pressing speed of 150 inches/minute. The 8-inch gas-heated container was operated at 700°F.

The die and die cone shown in drawing R-1923, Figure IV-2 of Appendix IV, were fabricated from H-12 tool steel. The die insert was fabricated from Duplicast EDX to withstand the high billet temperatures. The mandrels were made from AISI type T-1 tool steel. The mandrels had a taper of 0.001/inch of length to gradually reduce the diameter of the mandrel toward the tip which will reduce the extrusion drag on the mandrel. Descriptions of the extrusion tooling, mandrel, and mandrel sleeve are given in drawing R-1923. The mandrel sleeve performs the same function as described under .220 Swift barrel fabrication.

The billets were preheated in a gas-fired furnace for 3 to 4 hours with a slightly oxidizing atmosphere to the temperatures indicated in Table V. Short graphite plugs were placed in each end of the initial four extrusion billets during preheat to help reduce the oxidation of the mild steel center sleeve. Stainless steel plugs replaced the graphite plugs for the second group of billets. As can be seen in Table V, the mandrels and sleeves were preheated to about 425°F except for the mandrel and sleeve for extrusion 6L52 which was preheated to about 250°F and the mandrels and sleeves for extrusions 6L53 and 6L54 which were used at room temperature. A very poor liner ID surface resulted in 6L53 and 6L54 which was attributed to excess chilling of the billet liner from the unheated mandrels and sleeves.

The surfaces of the dies, cones, and mandrels were prepared for extrusion by baking on a coating of molydisulfide. The liner, dies, cones, and mandrels were lubricated with Fiske 604-D Modified* before each extrusion. The mandrels were preheated within the mild steel sleeves with the lubricant between the mandrel and sleeve in place.

After removal from the furnace the billet was quickly moved to the press and loaded. The last step just prior to extrusion was the insertion of the mandrel and sleeve into the billet with the press mandrel cylinder. This lessens the mandrel exposure time to the hot billet.

* A commercial hot extrusion lubricant.

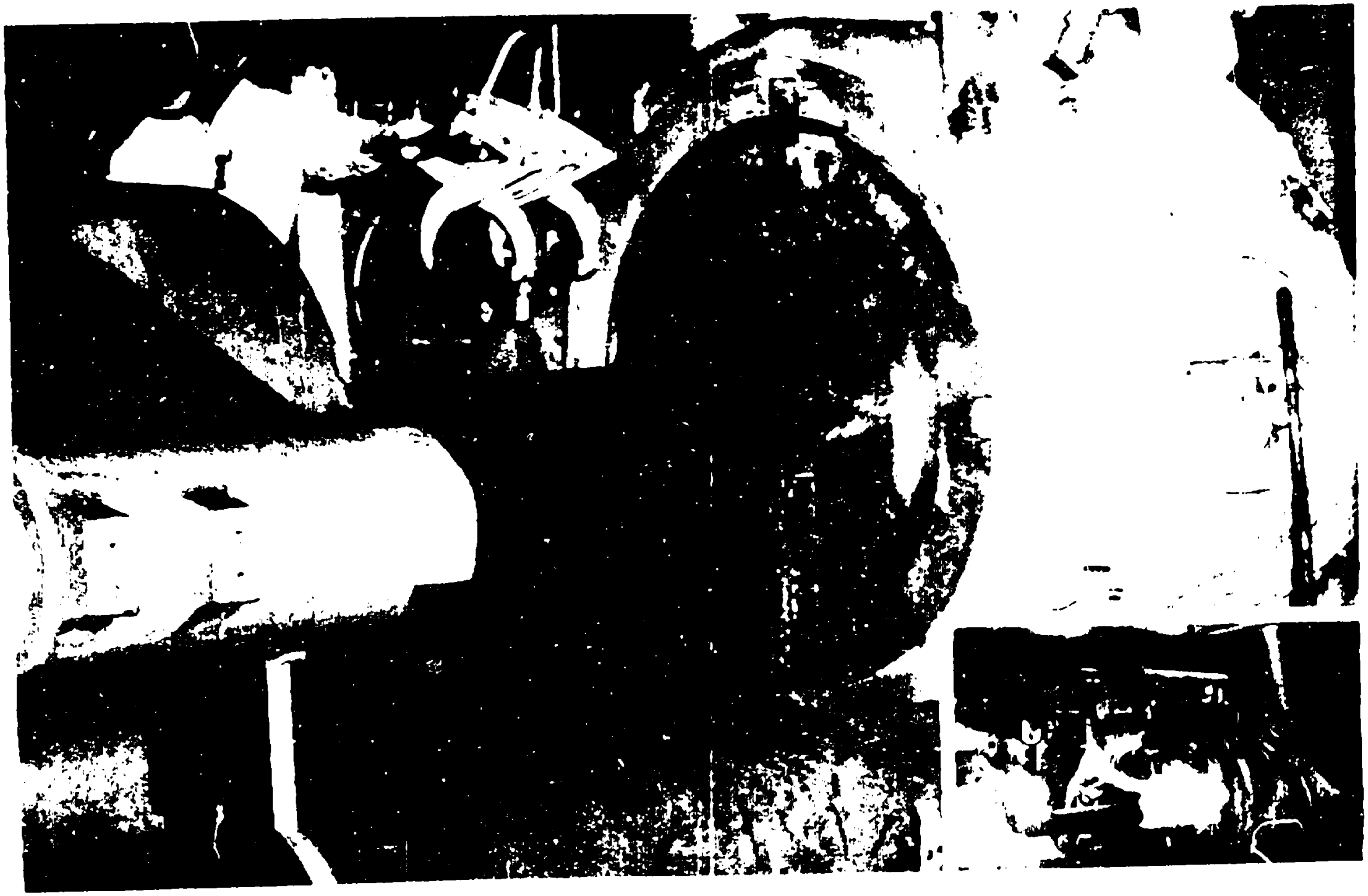


Figure 14. 3850-Ton RMI Press as the Ram is Closing on an Extrusion Billet (Billet Inside of Container). Inset Shows Hot 8-Inch-Diameter Billet Being Placed on the Press Billet Loader.

TABLE V. CONDITIONS AND RESULTS OF DUPLEX 25MM BARREL EXTRUSIONS (A-286 STEEL BARREL WITH L605 LINER)

Billet Number	Mandrel and Sleeve Preheat, °F	Billet Preheat, °F	Extrusion Diameter, in.	Area Reduction Ratio(a)	Ram Speed, in./min	Extrusion Force, tons Start	Extrusion Force, tons Run	Comments
6L51	400	2150	2.99	7.5/1	115	1908	1792	Some OD checking, fair bore surface, poor bond
6L52	200-300	2150	3.00	7.5/1	120	1978	1901	Extrusion split longitudinally
6L53	75	2040	2.99	7.5/1	130	2762	2490	Extrusion OD looked good, poor bore surface, poor bond
6L54	75	2040	2.99	7.5/1	130	2742	2490	Extrusion OD looked good, poor bore surface, poor bond
6L55	425(b)	2100	2.62	10.0/1	125	2684	2529	Fair bond - good bore surface
6L56(c)	425(b)	2100	2.62	10.0/.1	125	3110	2878	Transverse cracks in OD surface, fair, bond, good bore surface
6L57	425(b)	2088	2.62	10.0/.1	125	2800	2606	Few light cracks in OD surface, fair bond, fair bore surface
6L58	425(b)	2088	2.62	10.0/.1	125	2645	2490	Fair bond, fair bore surface

CONDITIONS:
1. Press - 3850-ton Loewy Press
2. Tooling temperature 700°F
3. Lubricant: Liner, dies, cones, and mandrels coated before each extrusion with Fiske 604D modified.
4. Billet outer diameter - 7-7/8 inches

Notes:
(a) Reduction ration based on billet and extrusion dimensions.
(b) Mandrels preheated inside sleeves with lubricant in place.
(c) Billet OD chilled during delay in loading.

The conditions and results of each extrusion are given in Table V, and extrusions 6L53 and 6L54 along with close-up views of their surfaces are shown in Figure 15. Extrusions 6L51 and 6L52 can be seen in Figure 16. Extrusion 6L52 shows a longitudinal crack which developed from a hot-short condition in the A-286 steel due to the billet preheat temperature being too high.

All extrusions were quenched in water immediately after extruding to maintain the A-286 steel in the solution condition. A delay of about 3 minutes after extrusion prior to quenching was used on extrusions 6L56, 6L57, and 6L58 to promote a wider diffusion zone between the A-286 steel and the L605 liner.

Blank Preparation

The extrusions were first straightened on a gap press to a straightness of 0.003 inch/foot on the OD surfaces. The extrusions were then cut to the desired blank lengths, and the mild steel mandrel and billet sleeve materials were chemically removed from the bores using a solution of 10 percent nitric acid. A transverse section of extrusion 6L55 after removal of the mild steel sleeves is shown in Figure 17.

Following the removal of the mild steel extrusion sleeves, the A-286 steel was age hardened by heating the barrel blanks to 1325°F and holding for 16 hours. Table VI shows the hardness of the A-286 steel barrel and the L605 liner before and after aging.

TABLE VI. HARDNESS OF A-286 STEEL AND L605 ALLOYS IN 25MM BARREL BLANKS AS-EXTRUDED AND AFTER AGING FOR 16 HOURS AT 1325°F

Barrel Number	Condition	A-286 Near OD	H-286 Near Liner	L605
6L55	As-Extruded	$79R_B$	$78R_B$	$99R_B$
6L56	Aged	$32R_c$	$32R_c$	$24R_c$
6L58	As-Extruded	$78R_B$	$78R_B$	$100R_B$
6L58	Aged	$31R_c$	$30R_c$	$24R_c$

The hardened blanks were checked for bore straightness and, if necessary, straightened. The OD was then rough turned to a diameter of about 2-1/2 inches to bring the OD concentric to the blank bore. A blank as aged and three blanks after rough machining the OD are shown in Figure 18.

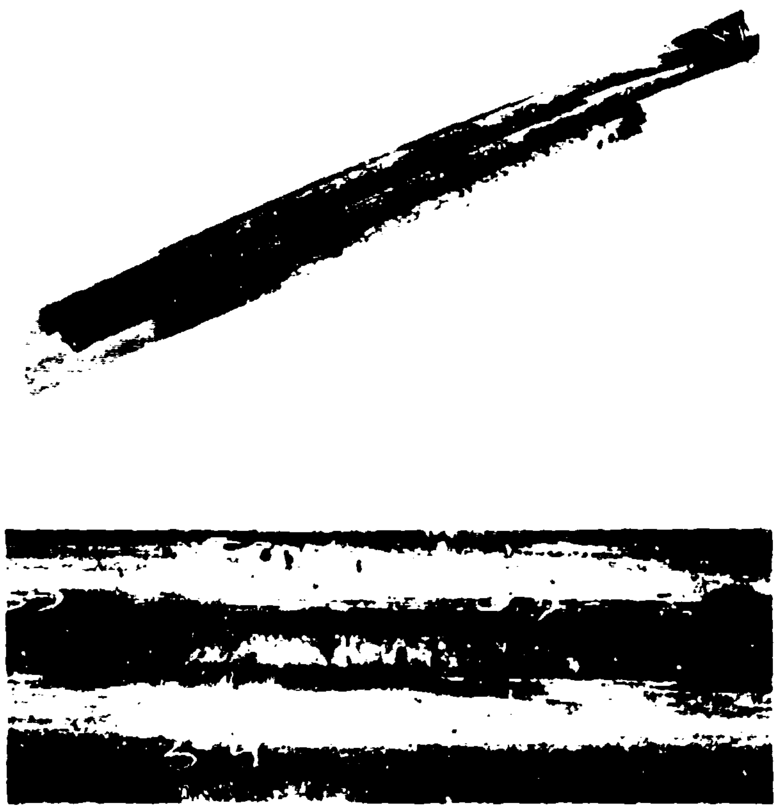


Figure 15. Extrusions 6L53 and 6L54 As-Extruded (Top) and a Close-Up Showing the OD Surfaces (Bottom).

Figure 16. Extrusions 6L52 (Left) and 6L51 (Right). Note Longitudinal Crack in 6L52 Resulting from a Hot-Short Condition.

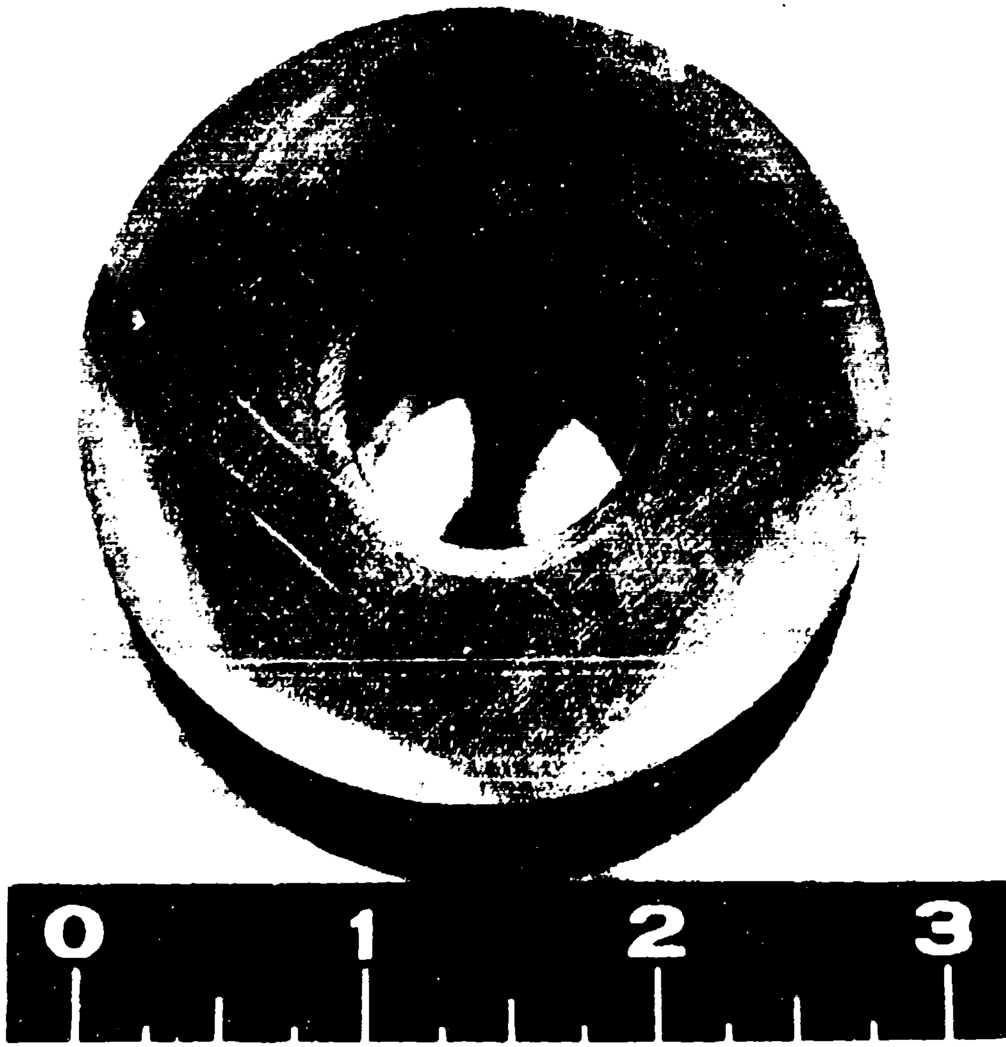
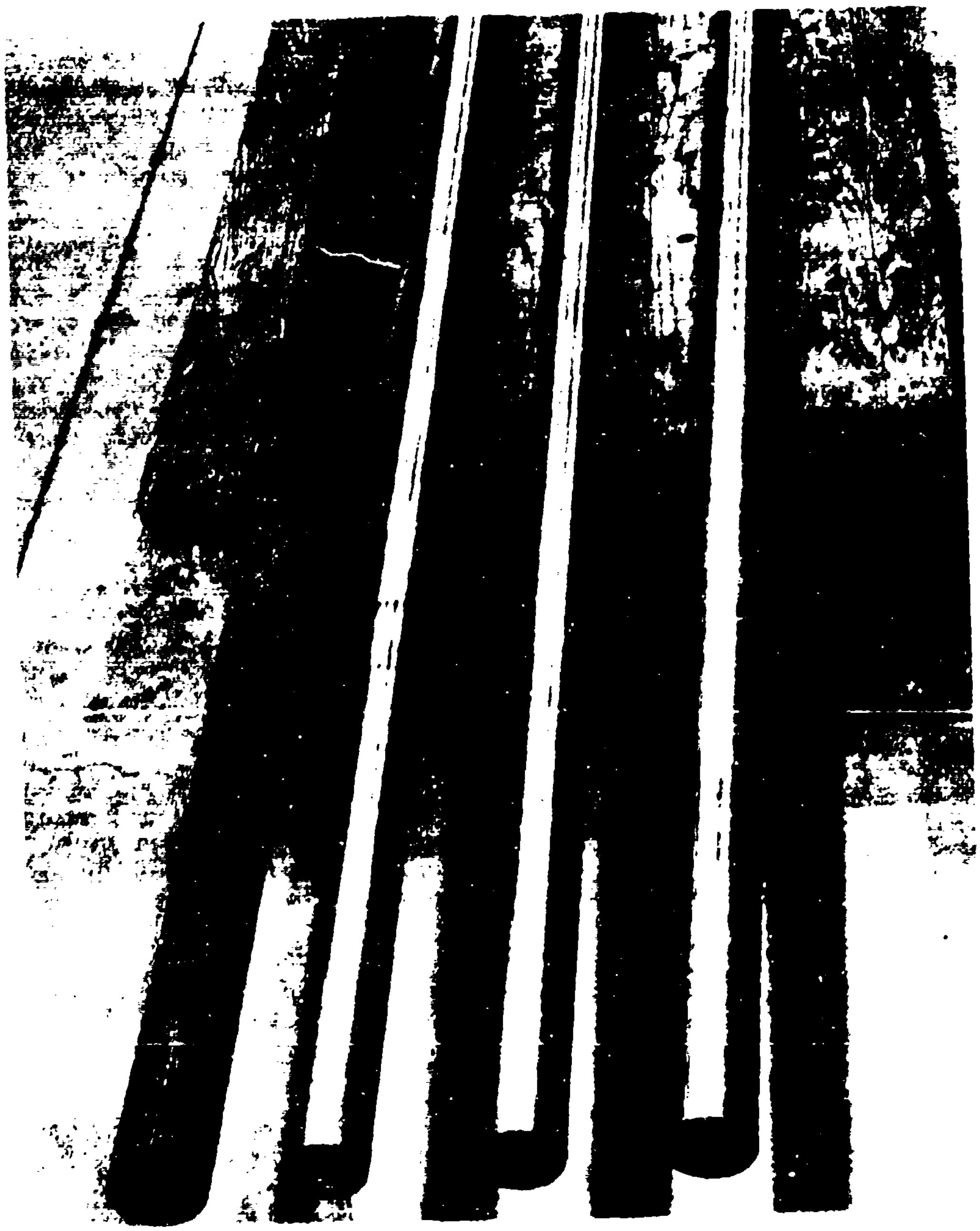


Figure 17. Section of Coextrusion 6L55 with L605 Liner After Removal of the Extrusion Sleeve Materials



Extrusions 6L55, 6L56, 6L57, and 6L58
(Left to Right)

Figure 18. One 25mm Barrel Blank in the As-Aged Condition and Three Barrel Blanks in the Aged and Rough Turned Condition

The barrel bores were machine honed to the GAU-7/A barrel bore size and finish machined by Clark and Wheeler Engineering Inc., Paramount, California. The barrel blank bores were honed from an average diameter of 0.945 inch to the 0.984 inch-bore diameter. With further coextrusion development and the use of a straight extrusion mandrel the liner bore diameter of the barrel stock could probably be extruded to within 0.010 to 0.015 inch of the finish bore diameter.

Rifling and Final Machining

The honed bores were rifled by Philco-Ford, Inc. using the barrel rifling approach developed for the homogeneous GAU-7/A barrel. A single point cutting tool was used to cut the rifling. The cutting tool was mounted to a stiff rod which was rotated by a cam action to generate the gain twist rifling. The L605 appeared to machine very satisfactorily by this approach, cutting sharp rifling with a very good finish. The rifling was in accordance with Philco-Ford drawing 47408, Figure IV-3 in Appendix IV.

The rifled barrel blanks were then machined to the requirements specified on Philco-Ford drawing 47408 (EM1 Gun). The blanks were first rough turned to near the final dimensions, and the straightness was checked and corrected, if necessary, before machining to the final dimensions. The completed barrels are shown in Figure 19.

Final Inspection

Final inspection of the three completed 25mm barrels was performed by Philco-Ford, Inc. The final inspection report is included in Appendix VI. The rifling was air gaged and the results are included in this report. The external contour dimensions were checked by conventional inspection tooling.

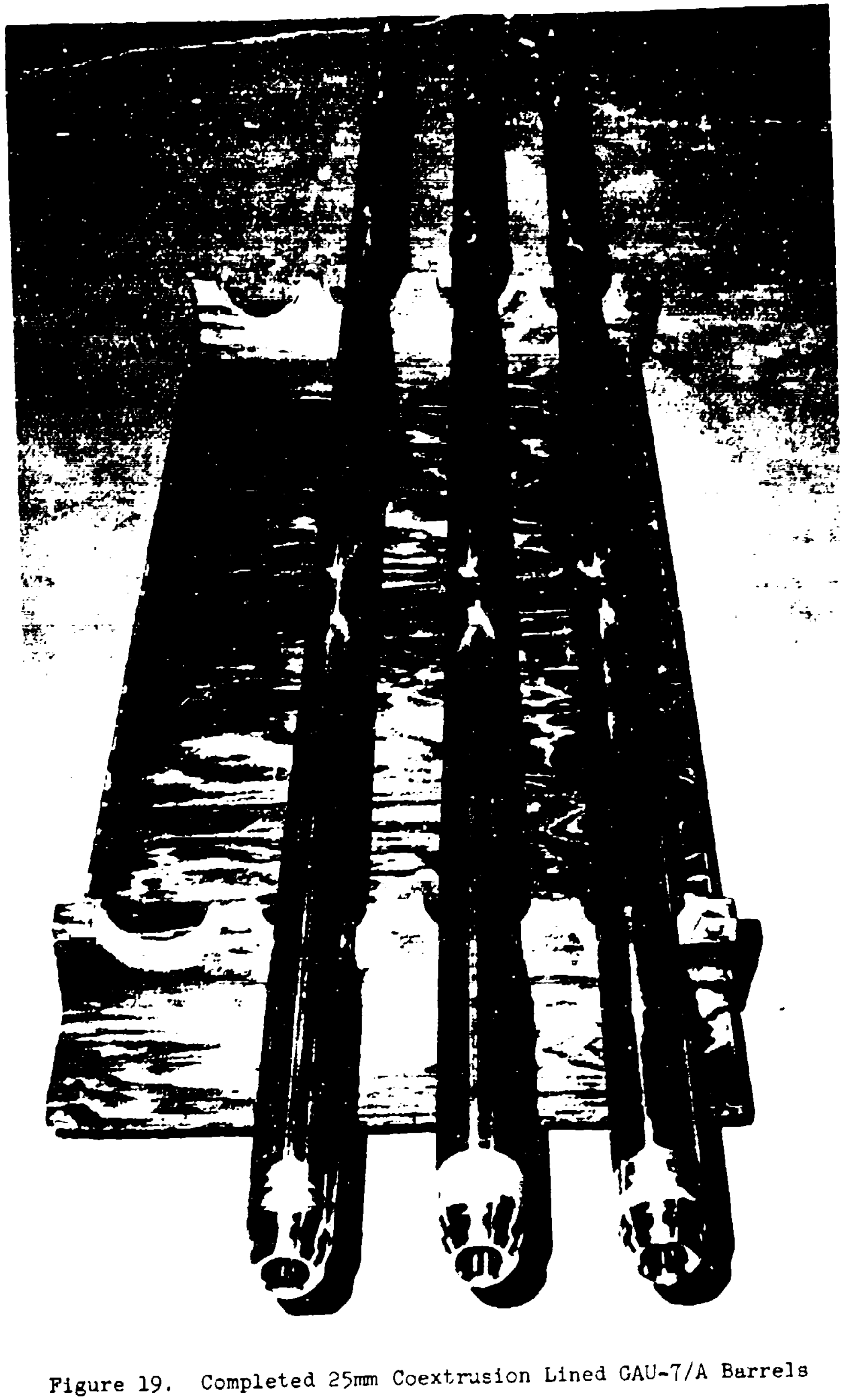


Figure 19. Completed 25mm Coextrusion Lined GAU-7/A Barrels

SECTION VI

DISCUSSION

.220 SWIFT BARREL FABRICATION

A total of 15 billets were extruded in this program, of which three had a TZM liner, three had a Mo-0.5Ti liner, four had an L605 liner, three had a Ta-10W liner, and two had a T-222 liner. The TZM, Mo-0.5Ti, L605, and Ta-10W coextruded satisfactorily with the A-286 steel barrel material. The TZM and the Mo-0.5Ti billet materials were recrystallized to lower the strength and improve the ductility of these materials for coextrusion. Previous experience in coextrusion of these alloys showed that the material in the hot-cold worked and stress relieved condition would not coextrude satisfactorily with the A-286 steel as the strength and ductility mismatch was too great. The work is put back into the molybdenum liners during coextrusion producing a slightly coarser texture with an as-extruded hardness of about 270 diamond pyramind hardness (DPH).

A transverse and longitudinal view of coextruded barrel liners of TZM, Mo-0.5Ti, L605, and Ta-10W alloys and the interface between the liners and the barrel steel can be seen in Figures 20, 21, 22, and 23. The liner microstructures are shown in Figure 24. The samples were all from the coextruded stock used in producing the barrels supplied under this contract. The A-286 steel microstructure near the extrusion OD and the liner of extrusion MT3 are shown in Figure 25. The outer material cools more rapidly and thus has smaller grains.

As can be seen by the radiograph in Figure 7, the T-22 alloy would not coextrude with the A-286 steel and instead extruded in small lumps. The difference in strength between the steel and the T-222 alloy was too great, and the two materials would not flow simultaneously at the extrusion temperature. In an attempt to match the strength of the T-222 alloy, a CG-27 steel was substituted for the A-286 steel which has about 25 percent more strength at the extrusion temperature than the A-286 steel. The results were about the same with the exception that smaller more frequent lumps of T-222 were generated in the coextrusion. The T-222 material was fully recrystallized, but a hot worked stress relieved material may provide a slightly more ductile material with lower strength.

One problem encountered in this program was the preparation of the extruded barrel blank bores for rifling. The blank bore surfaces should have a finish nearly as good as desired in the finish bore to insure an acceptable finish after rifling. Initially, it was planned to bore out the billet and mandrel sleeve materials, removing just enough of the barrel liner to insure good clean-up of the surface. However, the boring tool did not follow the hole in the bore closely enough to provide uniform clean-up and maintain a uniform liner thickness. Also the Ta-10W would not bore as the tool seized to the material. The problem was overcome by extruding the barrel stock with a slightly larger bore size and chemically removing the billet and mandrel sleeves. The hole was then honed to the desired finish for swaging.

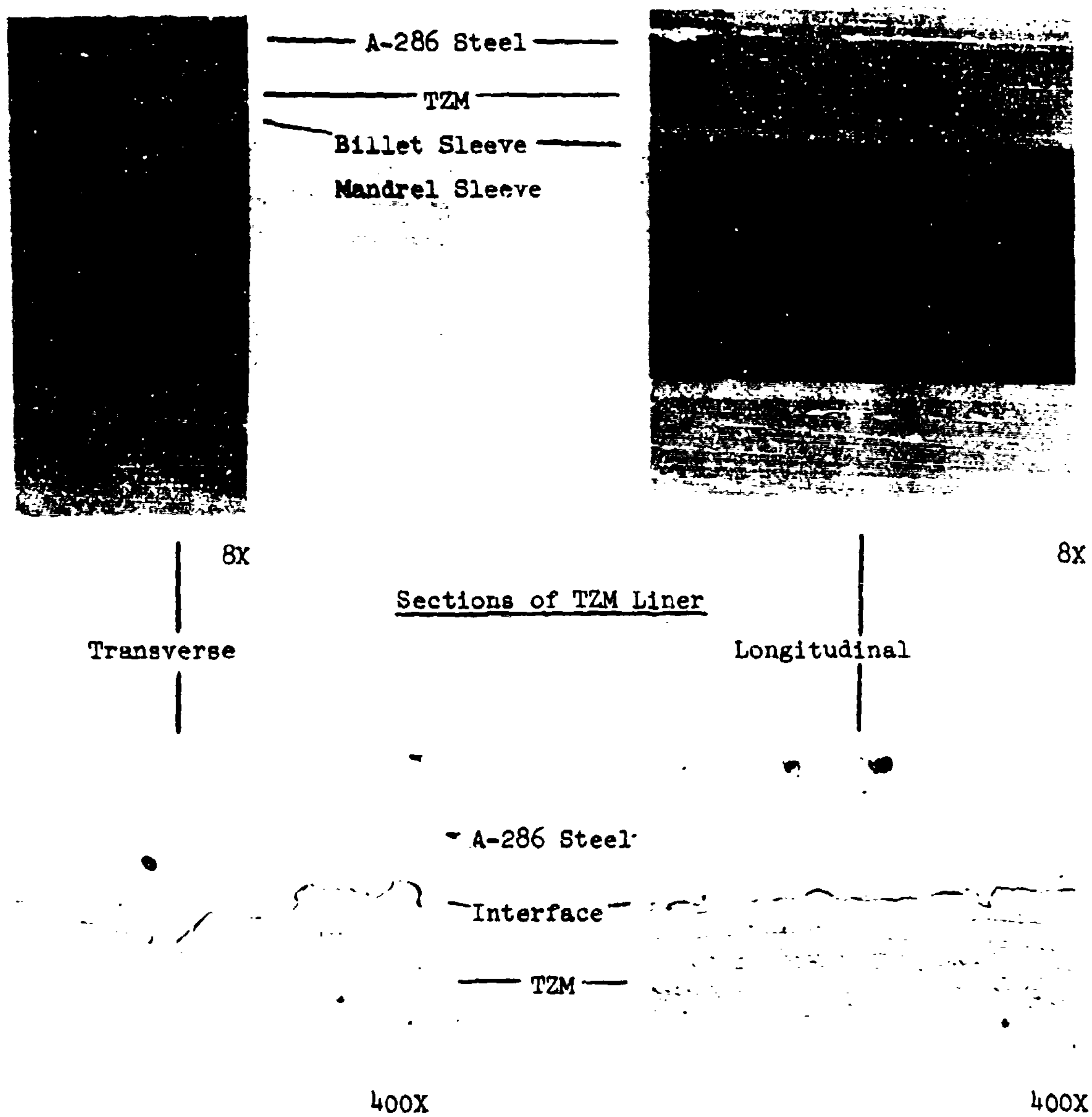


Figure 20. Sections of the As-Extruded Liner and Metallography Showing the Bond Line of Extrusion TM3

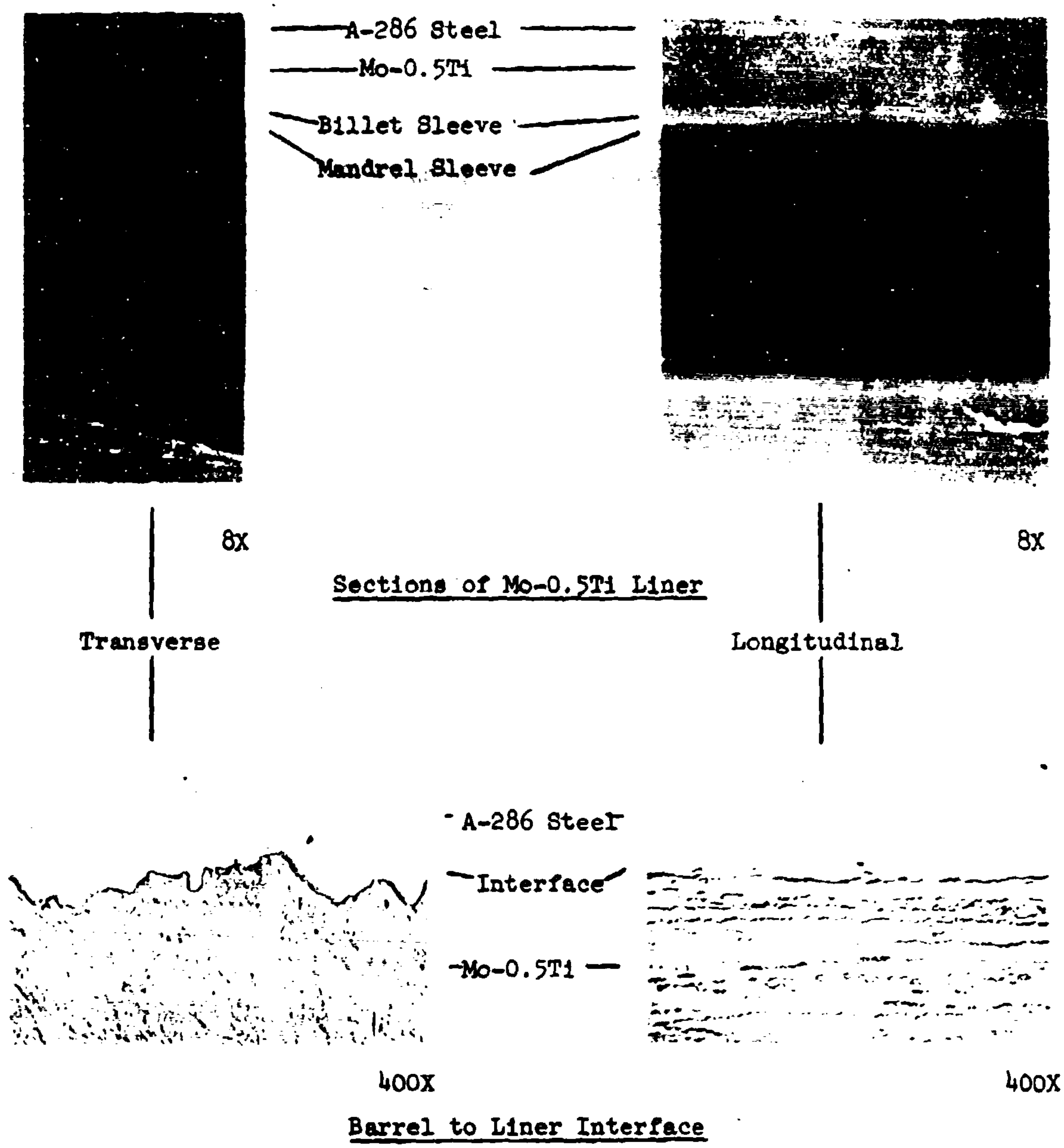


Figure 21. Sections of the As-Extruded Liner and Metallography Showing the Bond Line of Extrusion MT3

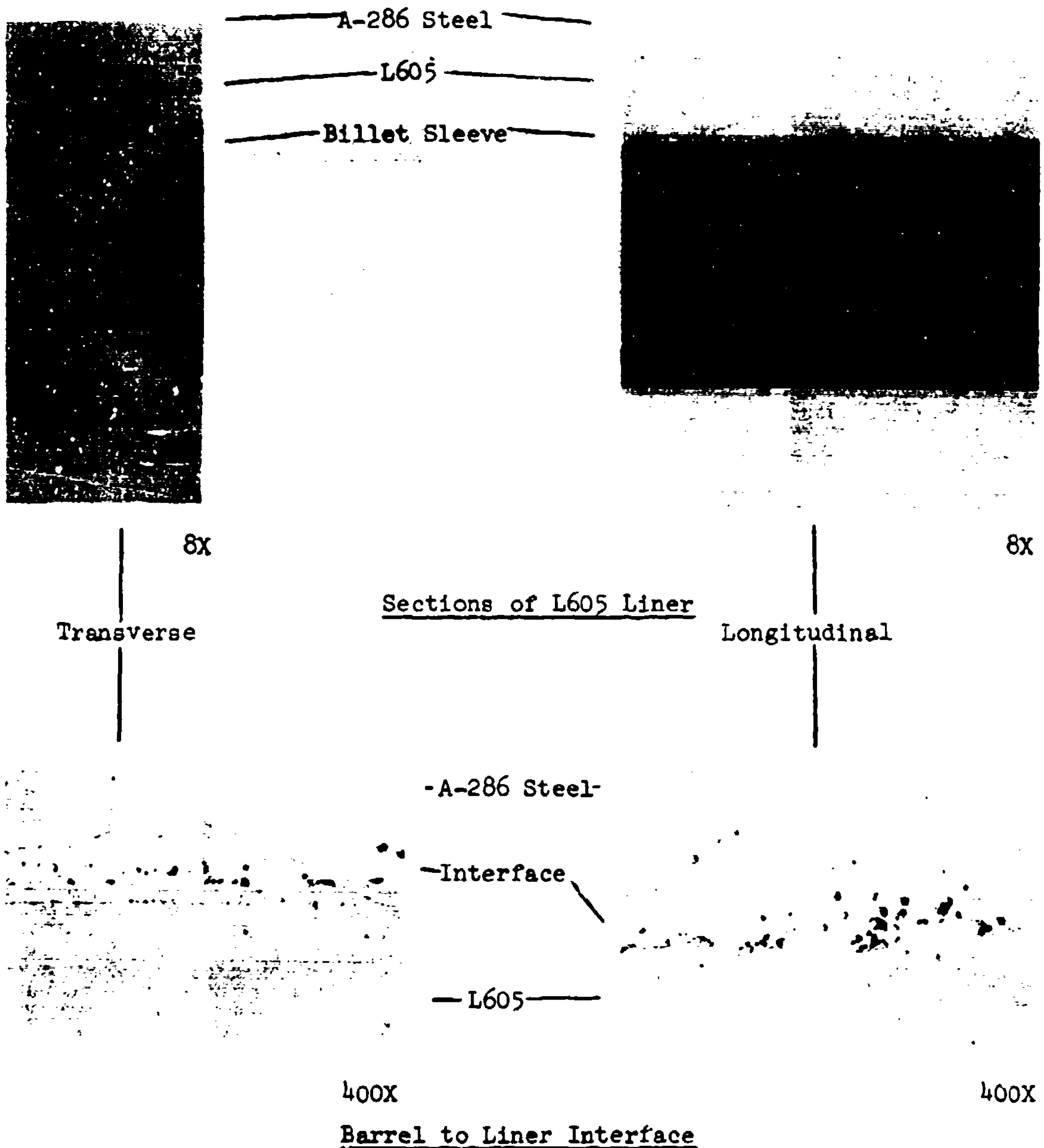


Figure 22. Sections of the As-Extruded Liner and Metallography Showing the Bond Line of Extrusion L54

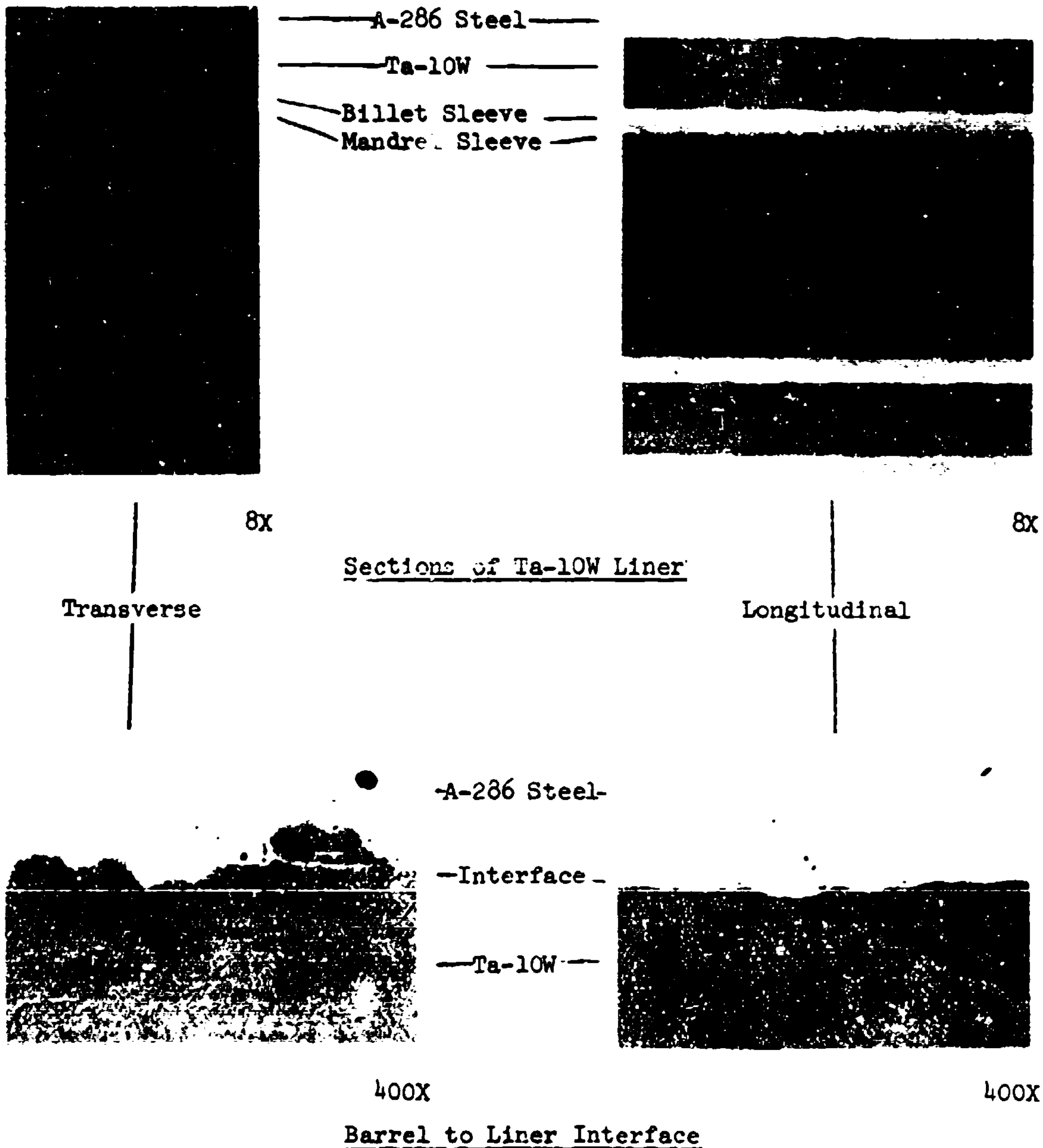
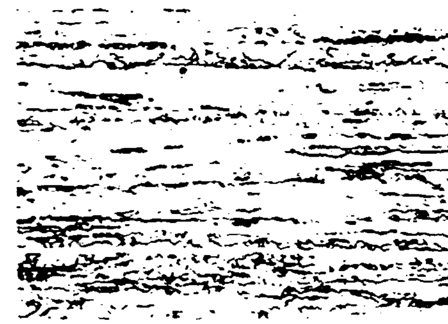


Figure 23. Sections of the As-Extruded Liner and Metallography Showing the Bond Line of Extrusion TW2

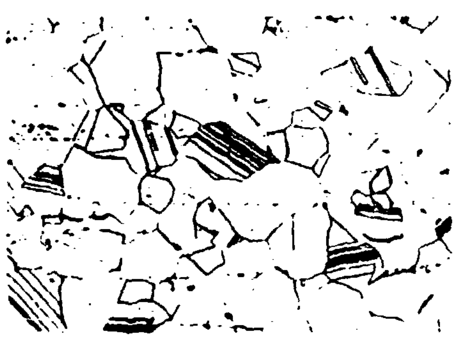
250X

Extrusion TM3
(TZM Liner)



250X

Extrusion MT3
(Mo-0.5Ti Liner)



250X

Extrusion L54
(L605 Liner)

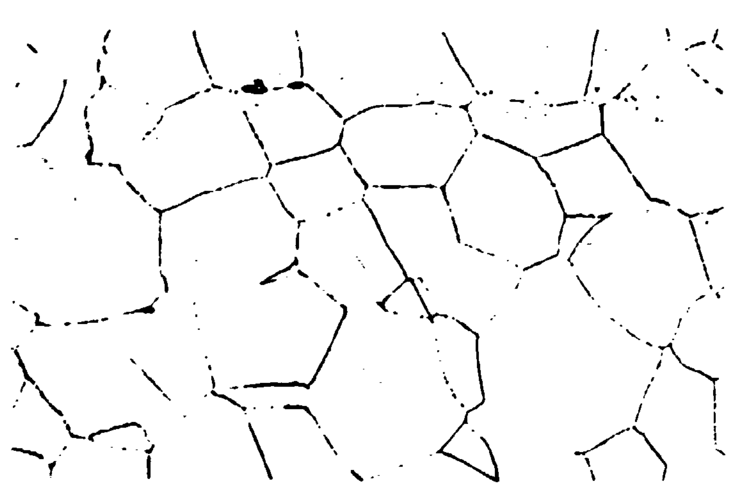
250X

Extrusion TW2
(Ta-10W Liner)

Figure 24. Metallography Showing the Longitudinal Liner Microstructure in Coextrusions TM3, MT3, L54, and TW2 As-Extruded

250X

Near Extrusion OD



250X

Near Liner

Figure 25. Microstructures of the A-286 Steel in Extrusion MT3 As-Extruded at 2100°F

The first two billets (TM1 and L51) were extruded at 2050°F. Rifling tests with the L605 lined material from L51 produced rifling with small cracks at the root of the rifling, as can be seen in Figure 26. A blank from this extrusion was annealed at 2200°F and quenched. Rifling test on this blank produced a crack-free rifling. The subsequent L605 lined extrusions were made at 2150°F, and no cracks in the rifling were apparent. A comparison of the L605 microstructures as-received in the solution condition, after extruding at 2150°F and after extruding at 2050°F, is shown in Figure 27. Note the significant difference in grain size between these three materials. The hardness of the as-received material was about 21 R_c, the hardness of the 2150°F extruded material was about 22 R_c, and the hardness of the 2050°F extruded material was about 25 R_c. During rifle swaging the hardness of the material increases to about 35 R_c.

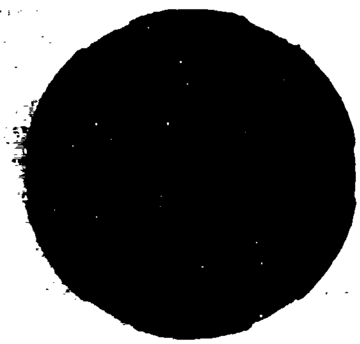
Difficulty was encountered in rifling the Ta-10W lined barrels as this material had a tendency to seize to the rifling mandrel and gall the bore even with a light graphite lubricant. By keeping the rifling mandrel coated with a thin film of Electrofilm 1000*, the tendency to gall was substantially reduced. However, this coating had to be replaced after swaging a few barrels. Further exploration of swaging lubricants is needed for this material.

25MM BARREL FABRICATION

The four billets in the first group were all preheated to 2150°F. The second extrusion split longitudinally, indicating a hot-short condition in the A-286 steel as can be seen in Figure 16. The temperature on the second and third extrusions (6L53 and 6L54) was then dropped to 2040°F and extruded providing good OD surfaces on these extrusions. The microstructures of the A-286 in the first extrusion (6L51) which was extruded at 2150°F and the fourth extrusion which was extruded at 2040°F can be seen in Figure 28. The microstructure near the OD of the extrusion shows about the same grain size for both extrusions while the grains near the liner in 6L51 are noticeably larger than the grains in 6L54 in the same location. This undoubtedly results from the extrusion container chill on the billets which reduces the temperatures significantly near the OD while not affecting the temperature of the material near the billet liner. The effect of the billet preheat temperature on the L605 grain size is also evident in Figure 29. The higher 2150°F preheat temperature of extrusion 6L51 resulted in considerably larger grains than in extrusion 6L58 which was extruded at 2090°F. The as-extruded hardness of the L605 was about the same for both extrusions.

The mandrels and sleeves were preheated for the first two extrusions but were not preheated for the third and fourth billets. The ID surfaces on the first two extrusions were fairly smooth after removal of the

* A solid film lubricant product of Electrofilm, Inc.



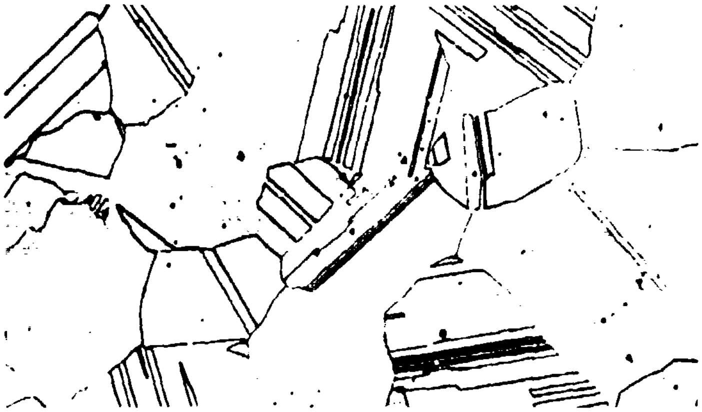
8X

Rifled Bore

50X

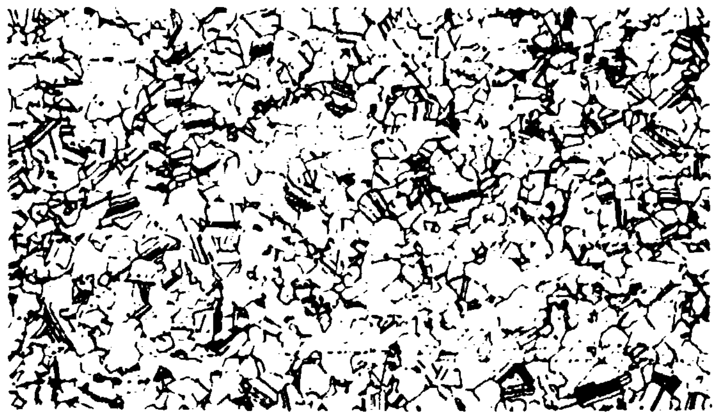
Close-Up of Rifling

Figure 26. Rifling in the L605 Liner of Coextrusion L51 Which was Coextruded at 2050°F. Note Cracks at Root of Rifling.

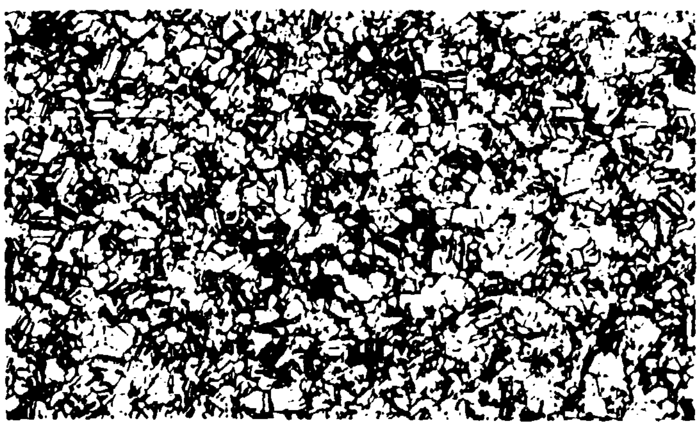


As-Received Material
(Solution Condition)

Extrusion L54
(2150°F Preheat)



100X



Extrusion L51
(2050°F Preheat)

100X

Figure 27. Comparison of the L605 Liner Material As-Received, Extruded at 2150°F, and Extruded at 2050°F

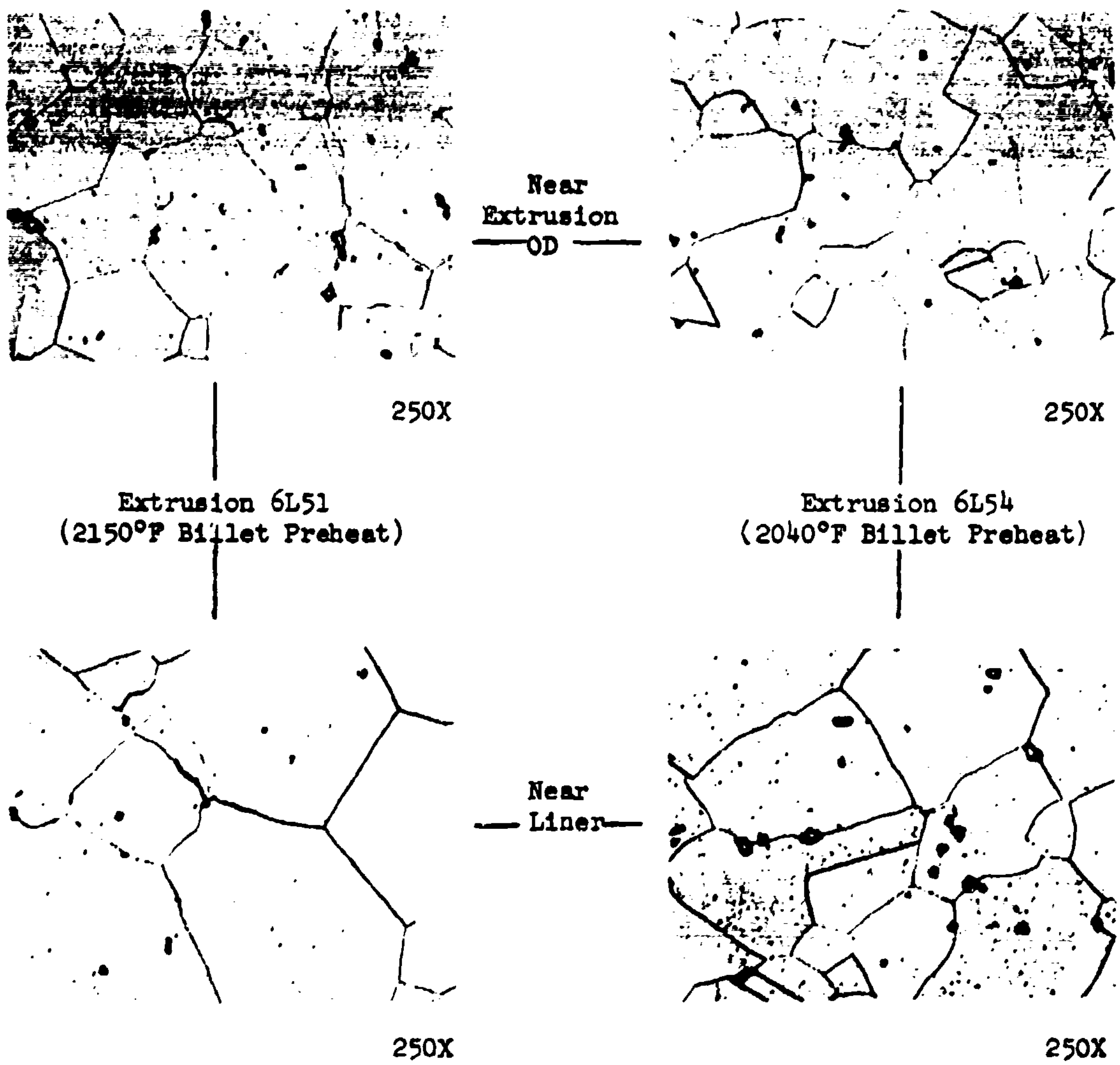
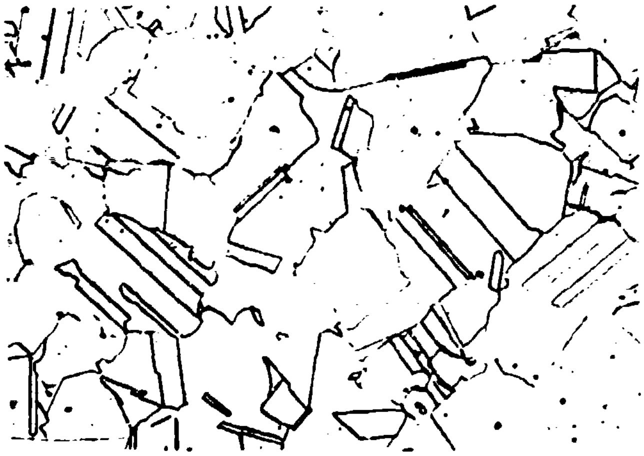
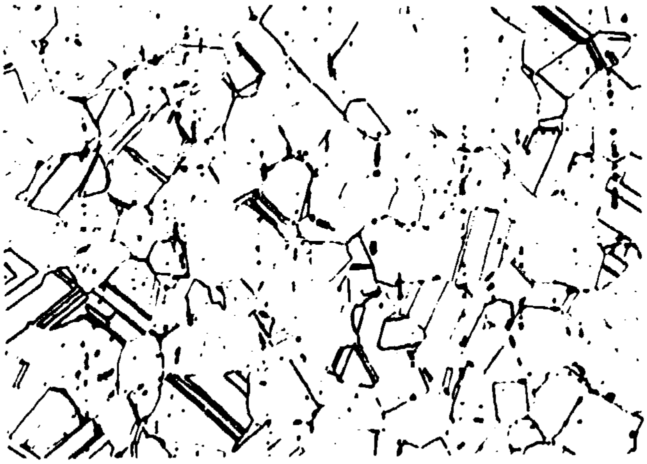


Figure 28. The A-286 Microstructures in Extrusions 6L51 and 6L54 Showing the Grains Near the Extrusion OD and the Liners



250X

Extrusion 6L51
(2150°F Billet Preheat)



250X

Extrusion 6L58
(2090°F Billet Preheat)

Figure 29. Microstructure of the L605 Liner in Extrusions 6L51 and 6L58

the extrusion sleeves, but the surfaces were very rough on the next two billets. Examination of the surfaces on the second two extrusions indicated that the L605 liner bore material had chilled sufficiently that it did not flow smoothly but tended to tear and extrude with a rough surface. This indicated the necessity for preheating the mandrels and sleeves for each extrusion.

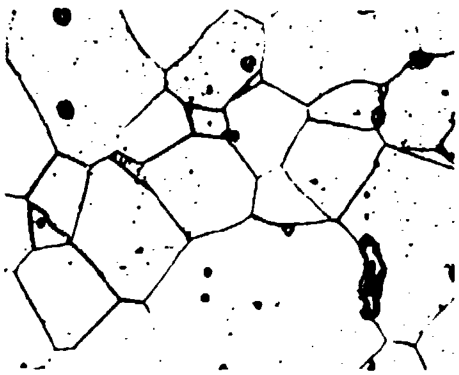
Examination of the first four extrusions revealed that all appeared to have poor bonds between the barrel steel and the liner, indicating possible leaks in the billets during preheat. The leaks may have resulted from failures in the billet seal welds or possibly the graphite plugs which were placed in each end of the billet to protect the center sleeve from excess oxidation may have reacted (carbon-iron eutectic reaction), with the steel center sleeve causing the billets to leak.

To improve the liner ID surface of the Phase II extruded barrel stock, the wall thickness on the center sleeve was increased 0.020 inch to help reduce the chill on the L605 billet liner from the mandrel and sleeve. Also the mandrel and sleeve were all preheated to about 425°F for each extrusion. The billet preheat temperature was changed to 2100°F which was low enough to prevent hot-shortness in the A-286 steel, yet high enough to leave L605 liner in a condition which would easily machine rifle.

To lessen the possibility of a poor bond in the Phase II extrusions from billet leaks, a larger diameter end seal flex cap was used to provide a more flexible end cap to reduce the chance of cracking a seal weld during preheat. Also the extrusion area reduction rates on the billet were changed from 7.5/1 to 10/1 which will further enhance bonding. The plugs which were placed in the billet ends to help prevent excessive oxidation of the mild steel billet center sleeves were changed from graphite to stainless steel to eliminate the possibility of an iron-carbon reaction.

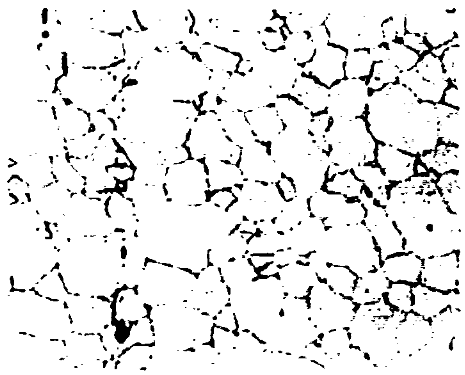
The above described changes made on the Phase II billets and extrusion procedures were beneficial in improving both the bond between the barrel and the liner and the surface of the barrel stock bores. Figure 30 shows the microstructure of the A-286 and L605 in extrusion 6L56 and the interface between the liner and the barrel. Figure 31 shows the interfaces for extrusions 6L57 and 6L58 and the microstructure of the A-286 in 6L57 and the L605 in 6L58.

The hardness of the L605 as-extruded was about 98 R_B and increased slightly to about 24 R_c during aging of the A-286 steel. Although the liner was readily machinable during rifling, a harder L605 liner may be desirable for longer barrel life.



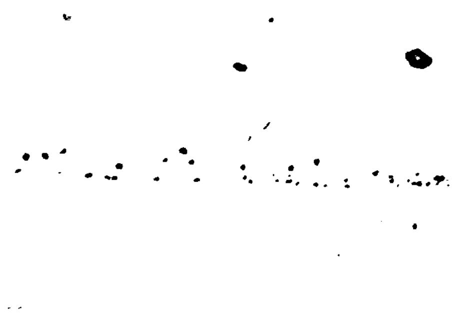
250X

A-286 Barrel Steel



250X

L605 Liner



—A-286

—L605

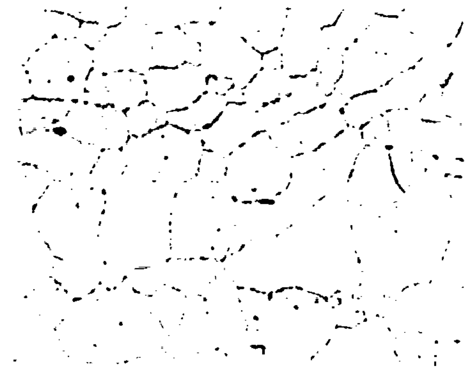
400X

Interface

Figure 30. Microstructures of the A-286 Steel and L605 Liner and the Interface Between These Materials After Age Hardening. Barrel Extrusion 6L56.

A-286 Steel

L605 Liner

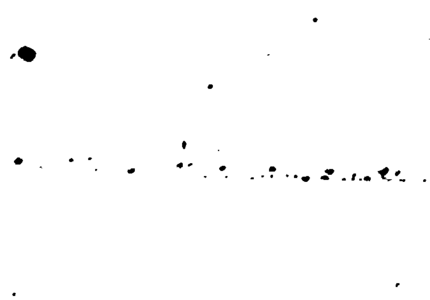


250X

250X

Extrusion 6L57
(As-Extruded)

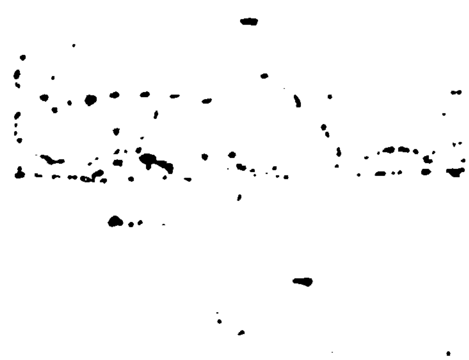
Extrusion 6L58
(After Aging)



A-286 Steel

Interface

L605 Liner



400X

400X

Figure 31. Microstructures of the A-286 Steel in Extrusion 6L57 As-Extruded and of the L605 Liner in Extrusion 6L58 After Aging at 1325°F Together with Views of the A-286 to L605 Interfaces

SECTION VII

CONCLUSIONS AND RECOMMENDATIONS

The .220 Swift barrel program demonstrated that both molybdenum alloys TZM and Mo-0.5Ti, the L605 alloy, and the Ta-10W alloy could be satisfactorily coextruded into barrel stock. However, the tantalum alloy T-222 would not coextrude satisfactorily. A possible solution would be to design the billet and a billet heating system such that the T-222 billet liner could be heated to a higher temperature than the steel. Also, an intermediate material between the steel and the T-222 in the billet which has a strength between the barrel steel and the T-222 liner at the extrusion temperatures may aid coextrusion.

Coextrusion of the 25mm barrel stock showed that the A-286 steel and L605 alloy combination which was coextruded into .22 caliber barrel stock could be coextruded into the larger 25mm barrel stock using the same basic coextrusion techniques. Other material combinations which where successfully coextruded to small bore barrel stock should also coextrude to larger bore barrel stock using the same basic techniques.

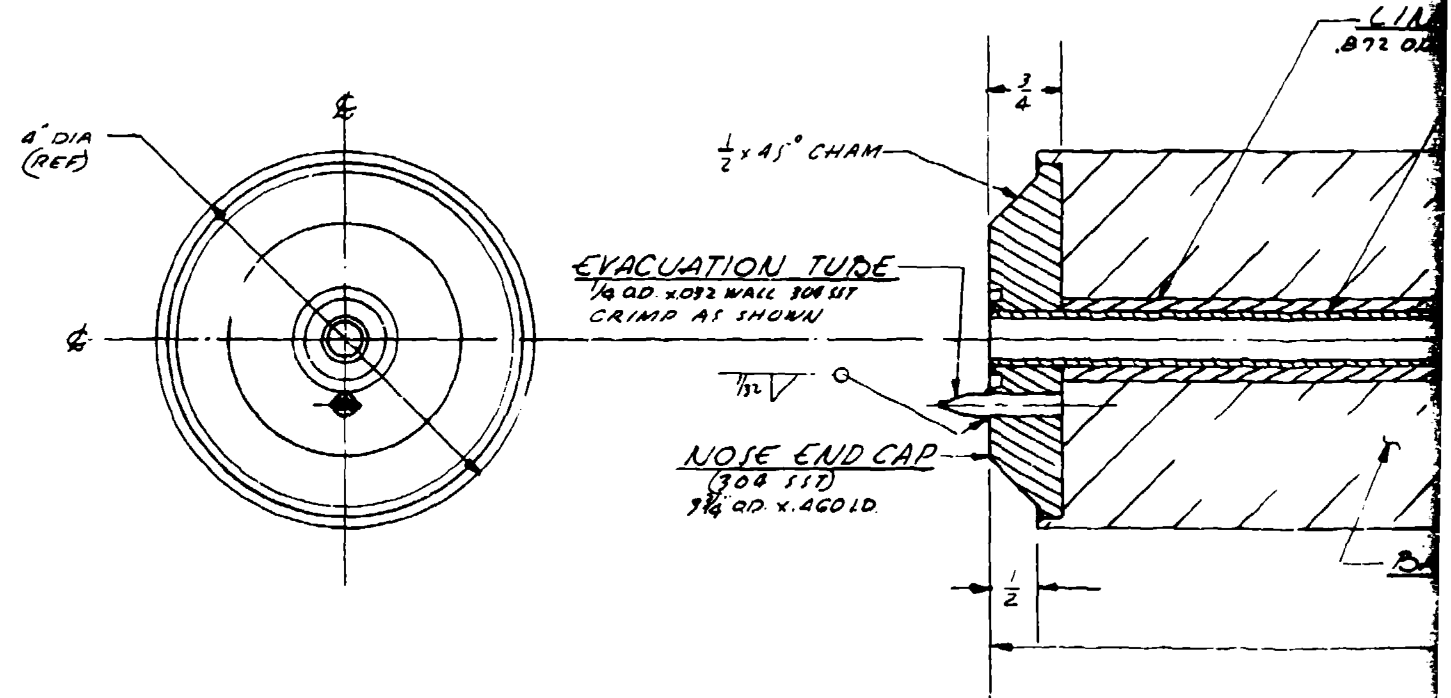
While barrel stock with a full length, fully bonded liner can be produced by coextrusion, subsequent operations are necessary to provide the desired finish and dimensions on the barrel liner bore. Honing was used to produce the desired finish on both the .222 Swift and 25mm barrel stock and was used to bring the 25mm barrel stock to the final bore size. Honing maintains the liner uniformity but is a very slow and costly operation, particulary for the tantalum and molybdenum alloys. An alternate approach which would be much faster than machine honing would be to abrasive jet hone the barrel blank bores after chemically removing the steel extrusion sleeves. A two-step operation may be required. The first step would use a coarse particle grit followed by a fine particle grit to obtain a good finish in the second step. Following the abrasive jet honing, the barrel could either be swage rifled or swaged over a smooth mandrel to the finish bore size if the rifling is to be machined into the barrel. Once this approach is established, the cost of the coextruded barrel should be substantially reduced.

The hardness of the L605 liner in the three completed 25mm barrels could be increased by coextruding the barrel blanks at a temperature of 2000°F or less and swage the blank bore to the desired diameter over a smooth mandrel rather than honing to size. The lower extrusion temperature plus the subsequent cold work should increase the hardness to about 30 R_c. The liner would be more difficult to machine rifle but may provide a barrel with a longer life. The above coextrusion temperature should be over 2100°F for L605 lined barrels if the barrel is to be swage rifled. This prevents cracks in the rifling that occurred in the .220 Swift barrels which were extruded at 2050°F. The softer material will work harden to over 30 R_c during swage rifling.

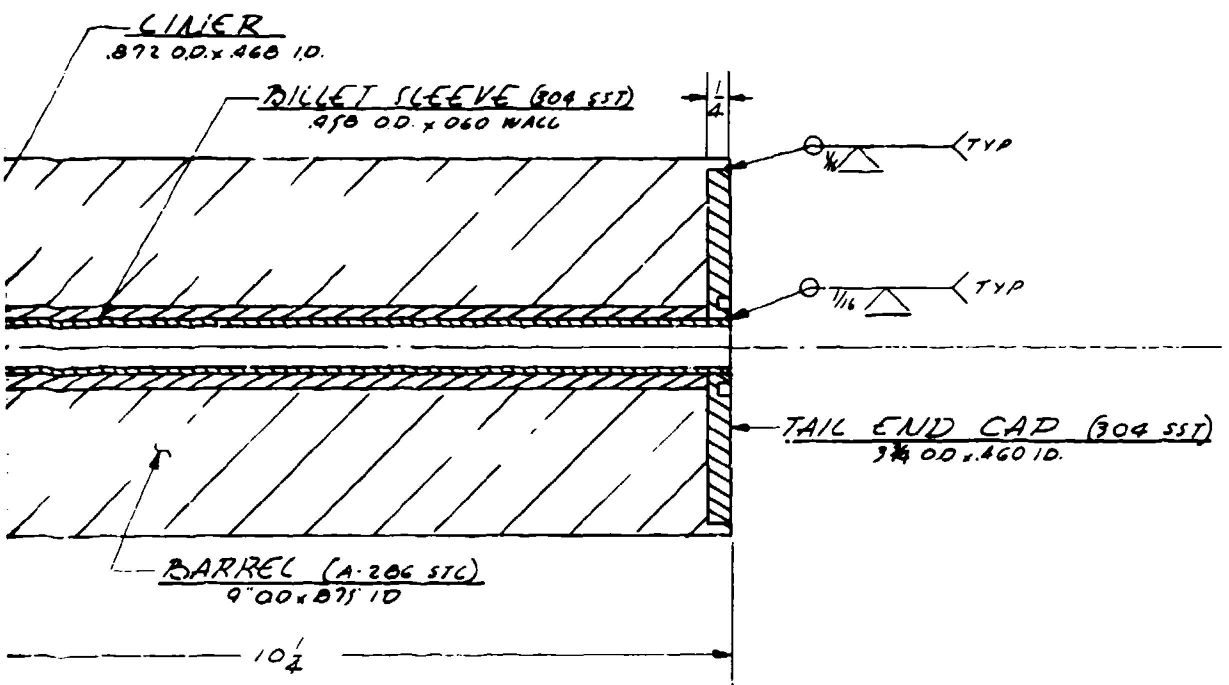
APPENDIX I

.220 SWIFT BARREL FABRICATION DRAWINGS

(The reverse of this page is blank)

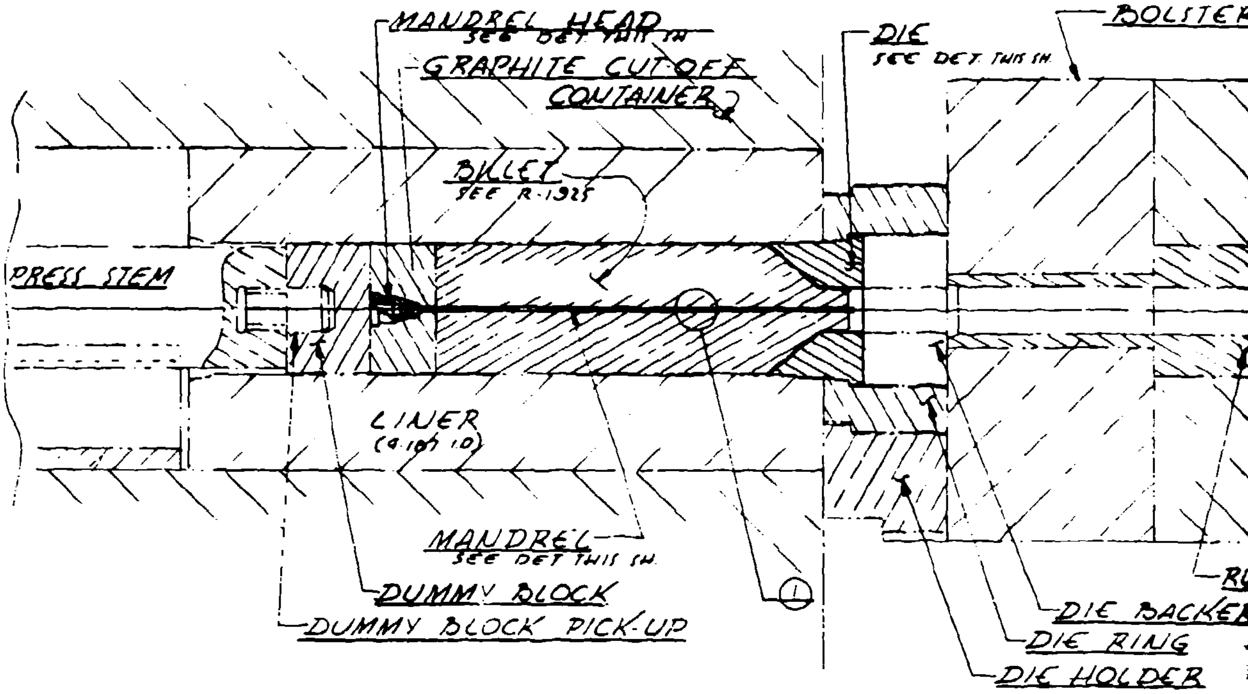


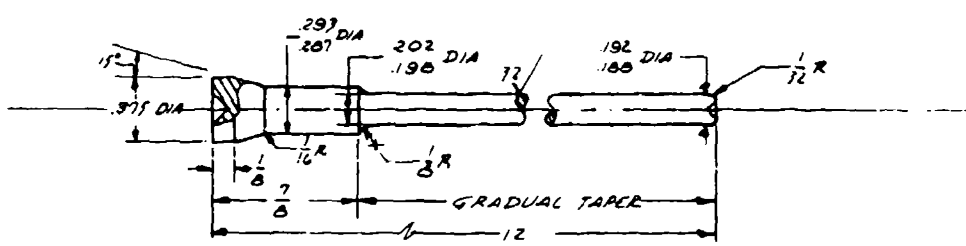
4" DIA
(REF)
$\mathbb{C}$
$\frac{3}{4}$
$\frac{1}{2}$ x 45° CHAM
EVACUATION TUBE
1/4 O.D. x .032 WALL 304 SST
CRIMP AS SHOWN
1/32
NOSE END CAP
(304 SST)
3 1/4 O.D. x .460 I.D.
$\frac{1}{2}$
.872 O.D



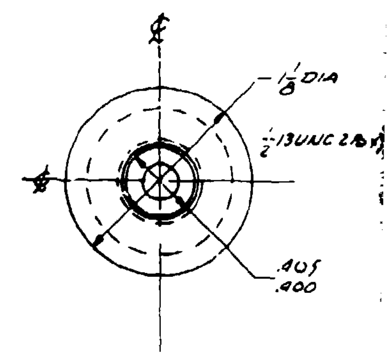
DWG NO R-1925 REV 0

Figure I-1. .220 Swift Duplex Barrel Billet

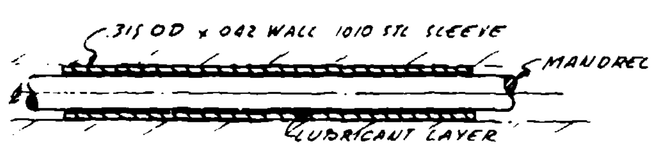




EXTRUSION MANDREL
MAT T-1 TOOL STL RC 57-60



EXTR



DETAIL 1

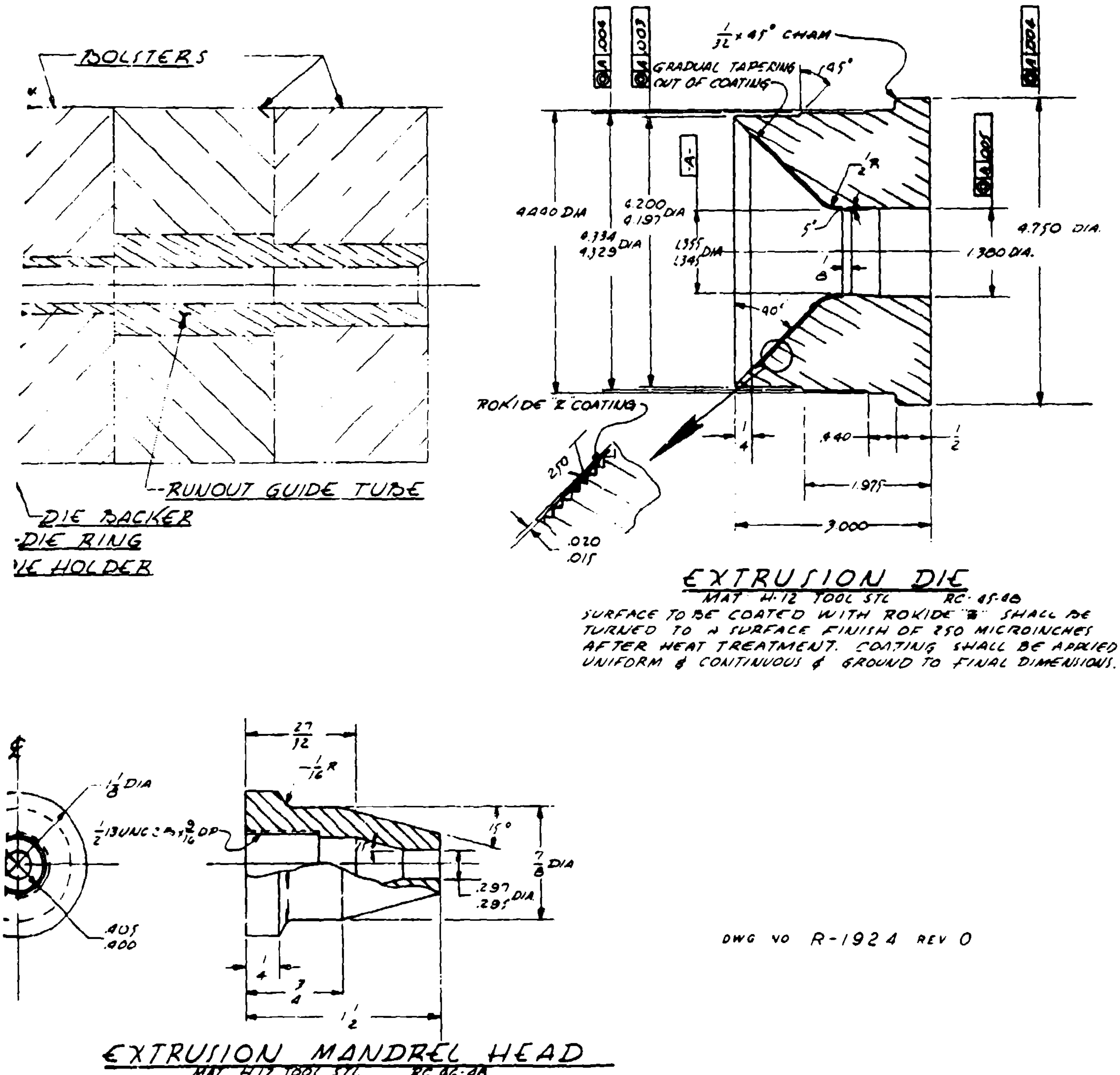
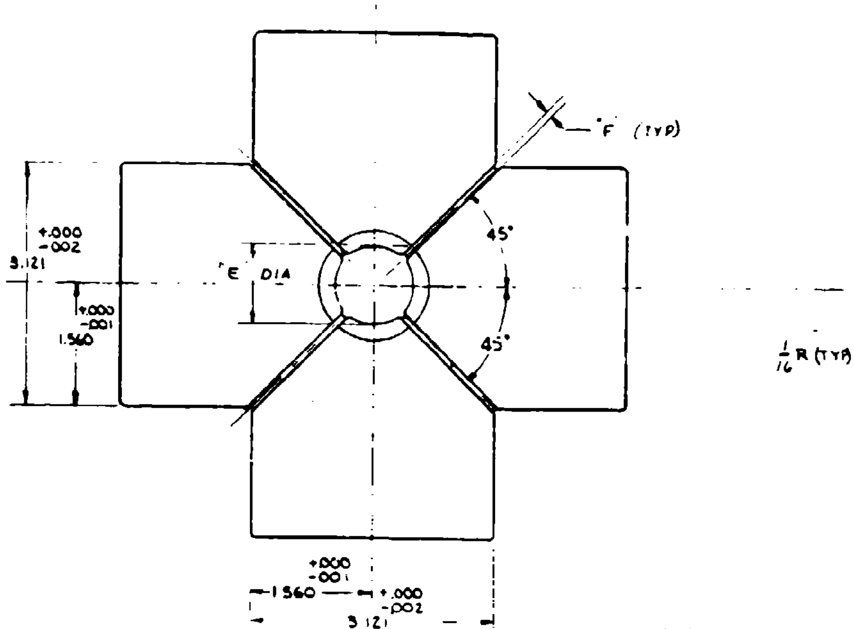


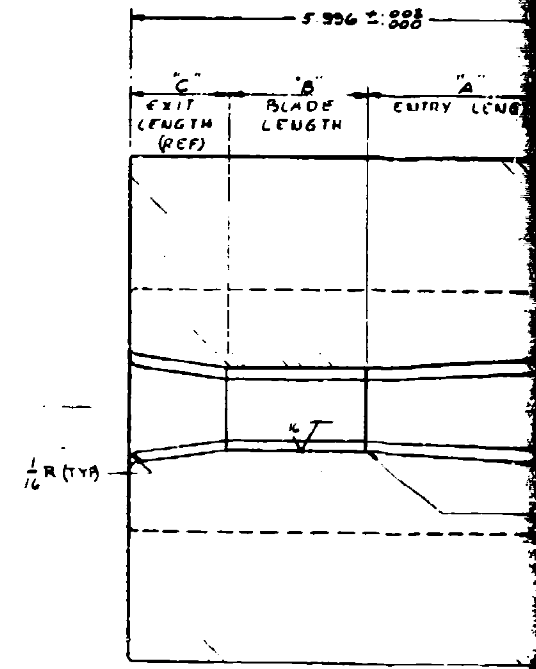
Figure I-2. .220 Swift Barrel Billet Extrusio[n] Assembly and Details

(The reverse of this page is blank)

2

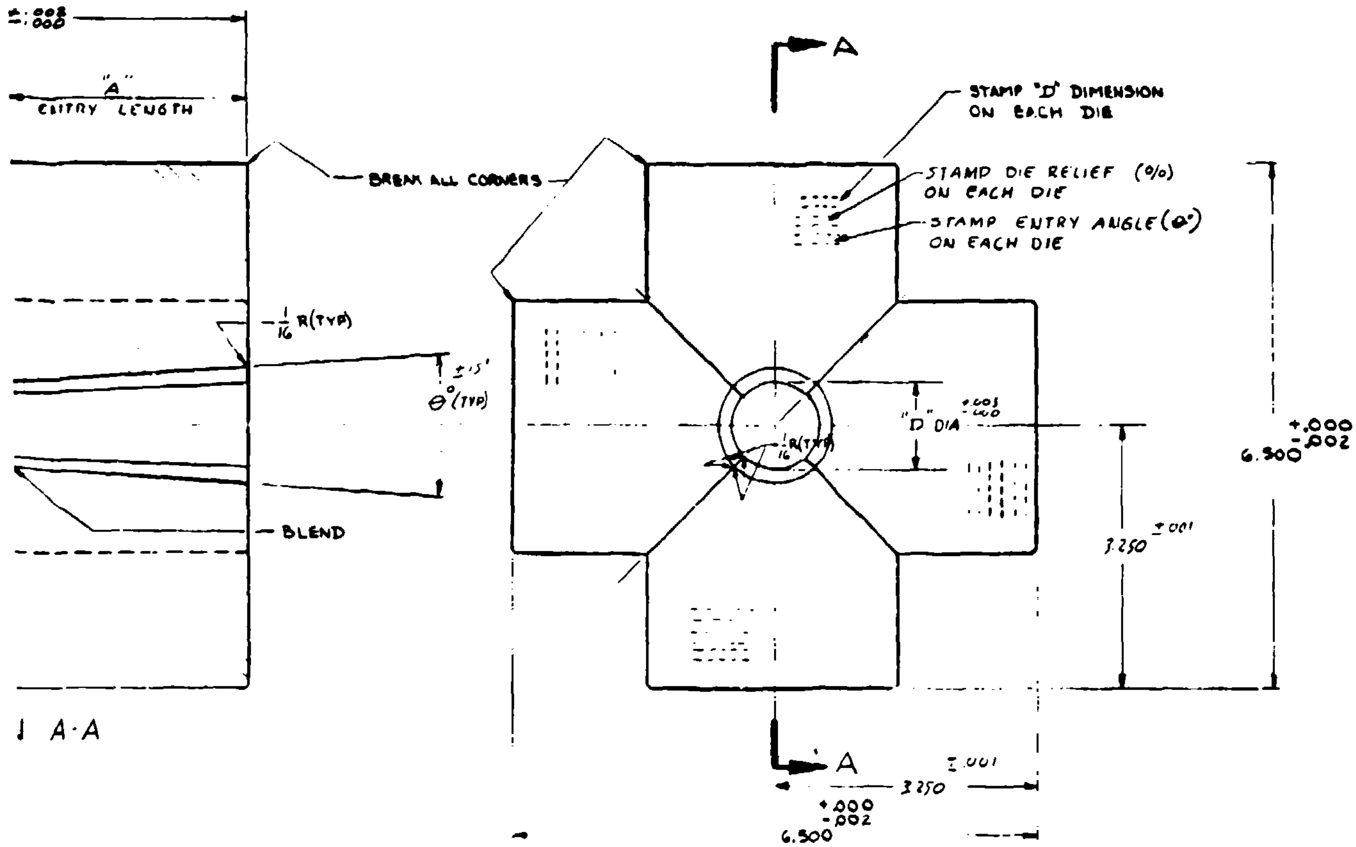


END VIEW FOR MACHINING DIA "E" & ∠ θ° USING TEMPORARY SHIMS



SECTION A-A

DIE SET NO.	A	B	C	D FINISH DIA	E BLADE DIA	ENTRY & EXIT ∠ (θ°) OF BLADE	F SHIM THICKNESS	DIE SIDE RELIEF °	MAT'L	HARDNESS RC
R-1	3"	1¼"	1¼"	1.240	1.324	8°	0.088	10	H-13	52-55
R-2	3"	1¼"	1⅛"	1.200	1.320	5°	0.085	10	H-13	52-55
R-3	2¼"	1½"	2¼"	1.200	1.320	8°	.005	10	H-13	52-55



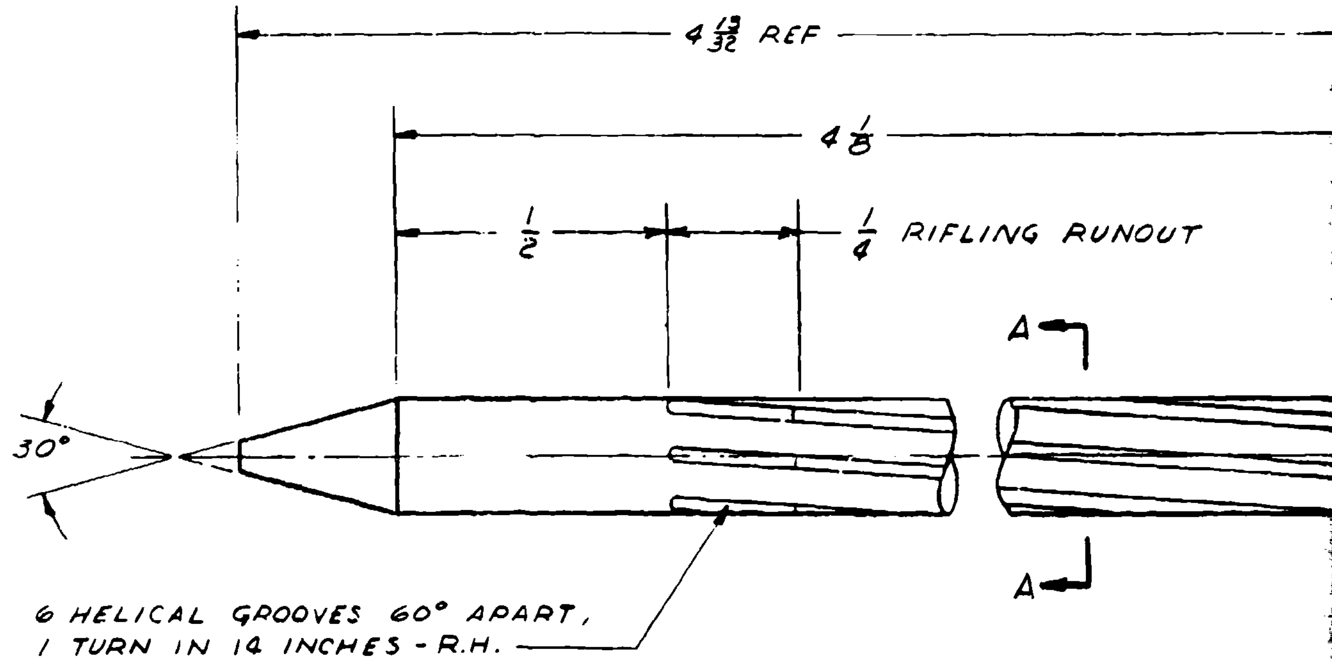
GENERAL NOTES
(UNLESS OTHERWISE SPECIFIED)
1 ALL MACHINED SURFACES 32/ SURFACE TEXTURE SHALL BE IN ACCORDANCE WITH USASI B46.1 (LATEST REV)
2 BREAK ALL EDGES .015 ±.010

DWG NO H-3-25648 REV 3

Figure I-3. High Temperature Dies for 4 Die Swage

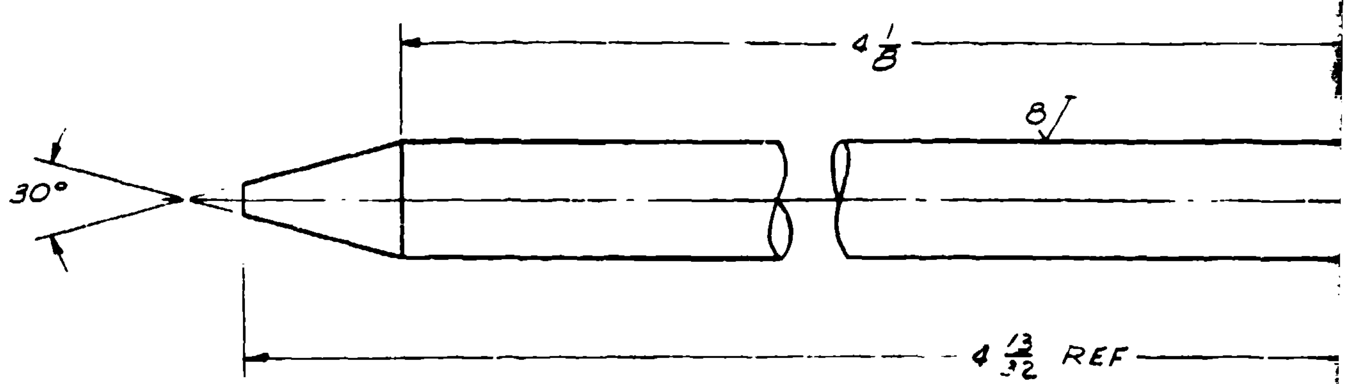
2

(The reverse of this page is blank)

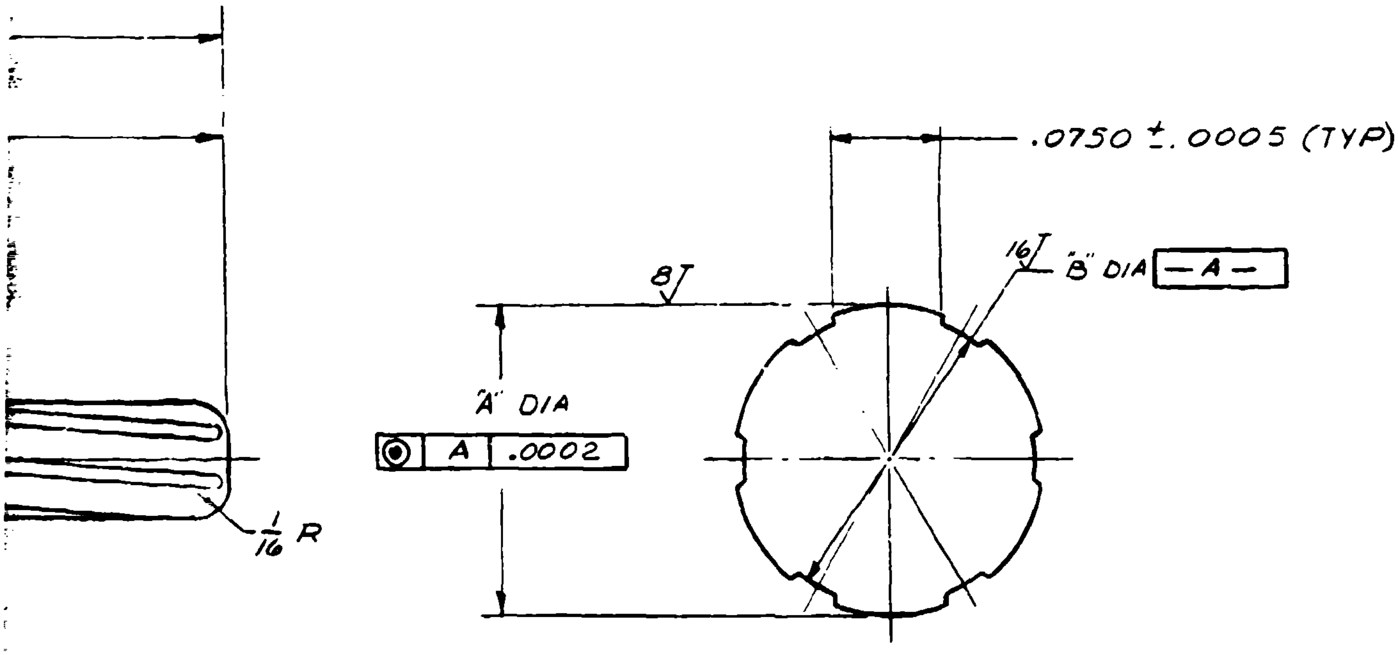


RIFLING MANDREL

PART	"A" DIA	"B" DIA	MATERIAL
1	.2240 +.0000 −.0005	.2190 +.0000 −.0005	CARBOLOY 55 B
2	.2230 +.0000 −.0005	.2180 +.0000 −.0005	CARBOLOY 55 B
3	.2235 +.0000 −.0005	.2185 +.0000 −.0005	CARBOLOY 55 B
4	.2245 +.0000 −.0005	.2195 +.0000 −.0005	CARBOLOY 55 B
5	.2250 +.0000 −.0005	.2200 +.0000 −.0005	CARBOLOY 55 B



6 SMOOTH MANDREL
CARBOLOY 55 B



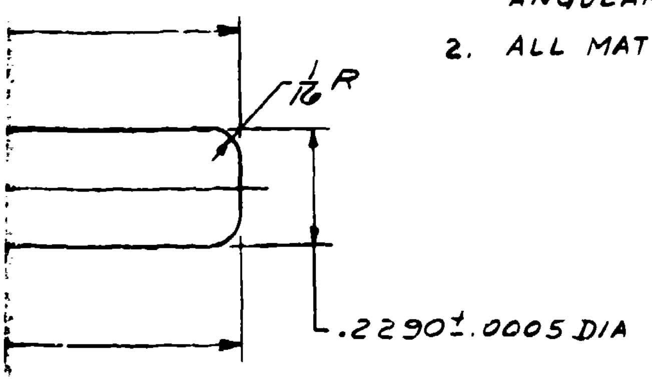
SECTION A-A

GENERAL NOTES

(UNLESS OTHERWISE SPECIFIED)

1. TOLERANCES: FRACTIONAL ± 1/64, DECIMAL ±.005 ANGULAR ± 0°30'.

2. ALL MATERIAL TO BE AS SPECIFIED.

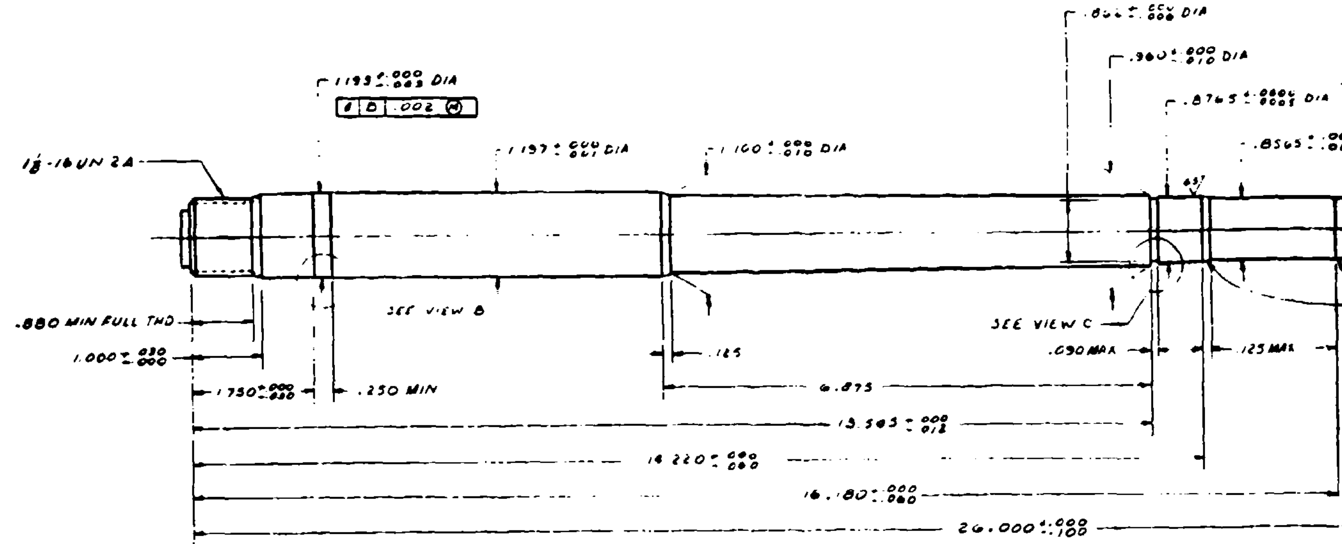


DWG NO. R-1493 REV 0

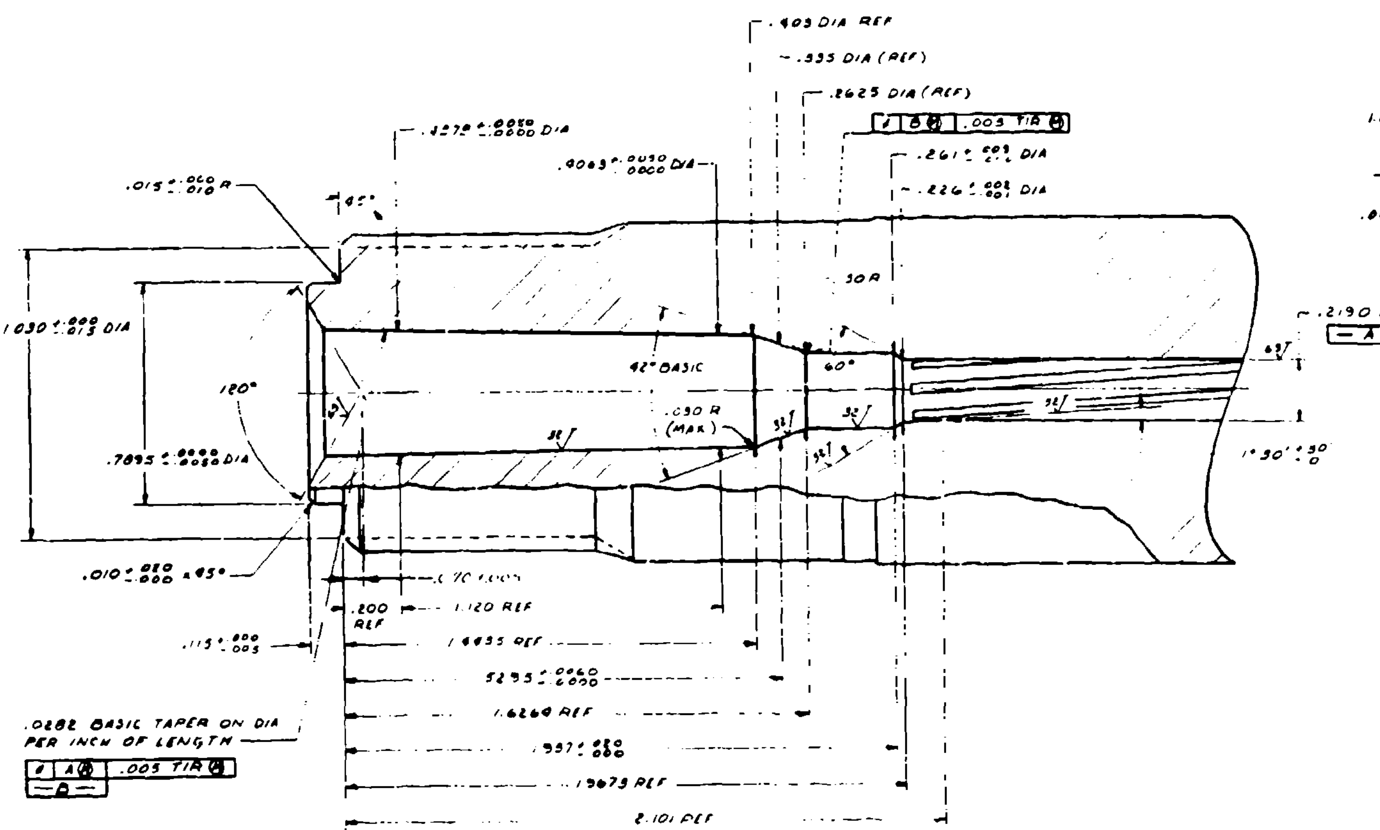
Figure I-4. .220 Swift Swaging Mandrel

2

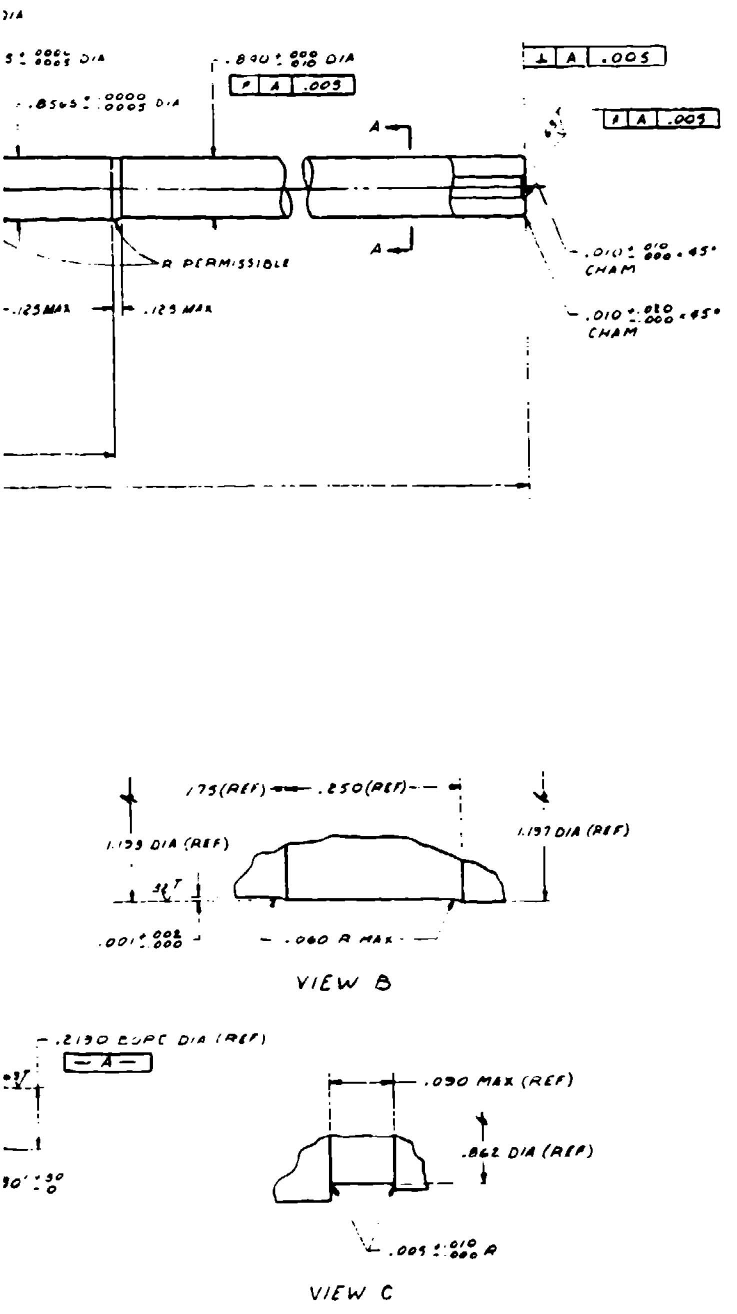
(The reverse of this page is blank)

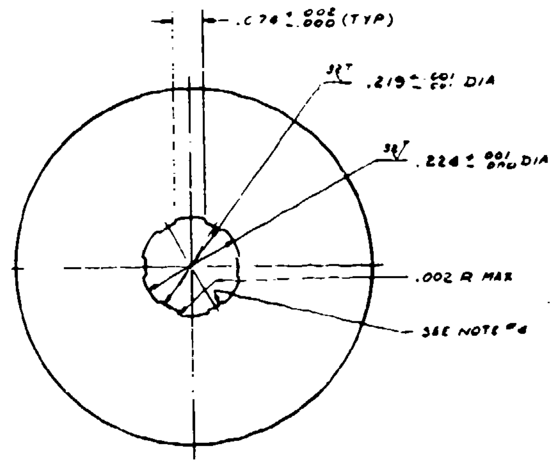


1⅛-16UN 2A
SEE VIEW B
SEE VIEW C
.880 MIN FULL THD
.250 MIN
.125
6.875
.090 MAX
.125 MAX



.409 DIA REF
.335 DIA (REF)
.2625 DIA (REF)
.50 R
42° BASIC
60°
120°
.030 R
(MAX)
.200
REF
1.120 REF
1.4435 REF
1.6269 REF
1.9673 REF
2.101 REF
.0282 BASIC TAPER ON DIA
PER INCH OF LENGTH





RIFLING SHALL CONSIST OF 6 GROOVES 60° APART, TOLERANCE NON-ACCUMULATIVE.
1 TURN IN 14 INCHES R.H.

SECTION A-A
(TYP)

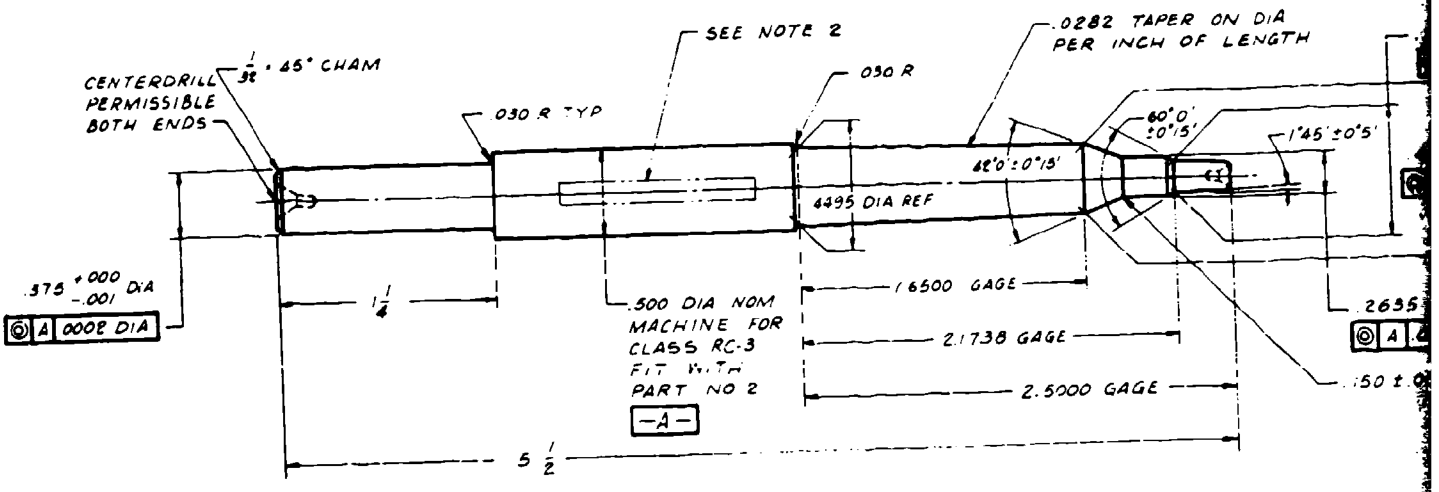
GENERAL NOTES
(UNLESS OTHERWISE SPECIFIED)

1. TOLERANCES: DECIMAL ±.005 ANGULAR ±0°30'.
2. ALL MACHINED SURFACES 125/. SURFACE TEXTURE SHALL BE IN ACCORDANCE WITH USASI B46.1 (LATEST REV).
3. BREAK ALL SHARP EDGES AND REMOVE ALL BURRS.
4. EDGES OF LANDS SHALL BE SHARP AND FREE FROM BURRS AFTER MACHINING.
5. ALL MAT'L SHALL BE AS SPECIFIED OR OF APPROVED EQUAL QUALITY.

DWG NO R-1492 REV 0

Figure I-5. .220 Swift Barrel

(The reverse of this page is blank)



(1) MAT- SOLID CARBIDE
GRADE C-2
4 OR 6 FLUTES

SCALE: 2/1

GENERAL NOTES (UNLESS OTHERWISE SPECIFIED)

1 TOLERANCES: FRACTIONAL $\pm\frac{1}{32}$ DECIMAL ±.005 ANGULAR ± 0°30'

2 IDENTIFY DWG NO B-82664 & PART NO R-1492 AT AREA INDICATED

3. DIMENSIONS MARKED "GAGE" SHALL BE TOLERANCED TO GAGEMAKERS STD TOLERANCES ALL OTHER DIMENSIONS SHALL BE INTERPRETED PER ANSI Y14.5

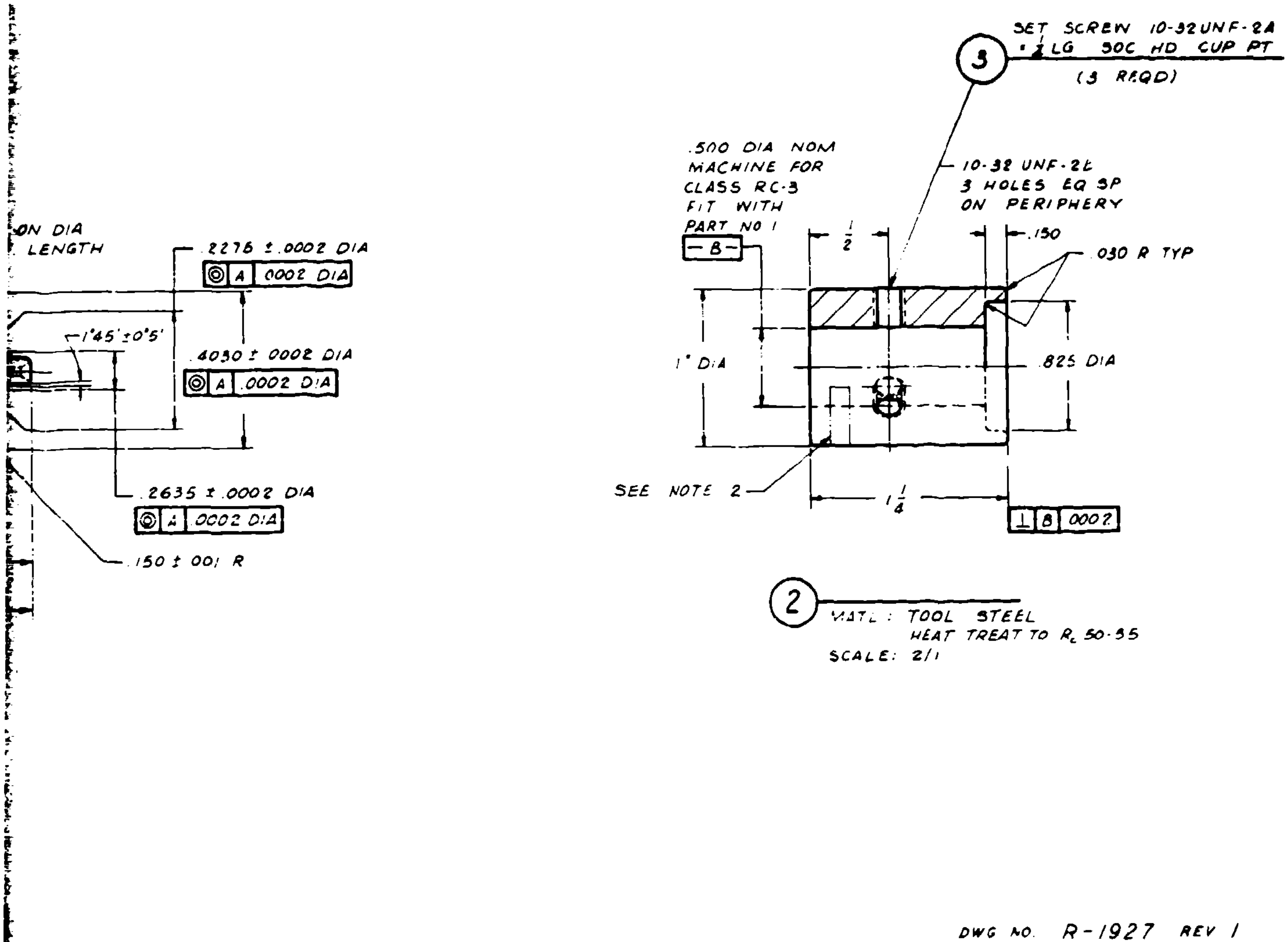
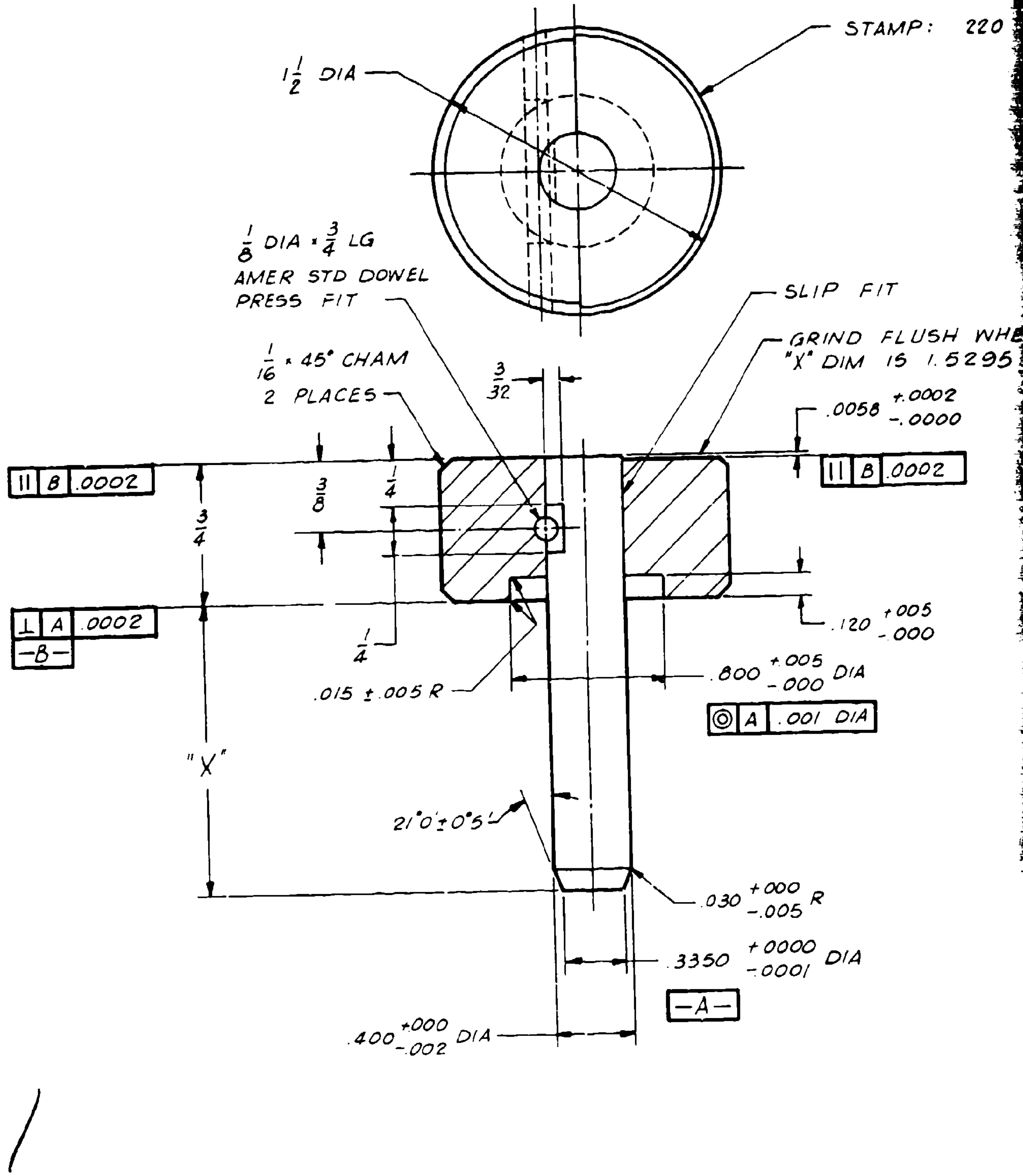


Figure I-6. Finish Reamer (Reference Drawing R-1492, Figure I-5. .220 Swift Barrel)

2

(The reverse of this page is blank)


STAMP: 220
1 1/2 DIA
1/8 DIA x 3/4 LG
AMER STD DOWEL
PRESS FIT
SLIP FIT
GRIND FLUSH WHE
"X" DIM IS 1.5295
1/16 x 45° CHAM
2 PLACES
3/32
.0058 +.0002 -.0000
// B .0002
// B .0002
3/8
1/4
3/4
⊥ A .0002
-B-
1/4
.120 +.005 -.000
.800 +.005 -.000 DIA
.015 ±.005 R
◎ A .001 DIA
"X"
21°0' ± 0°5'
.030 +.000 -.005 R
.3350 +.0000 -.0001 DIA
-A-
.400 +.000 -.002 DIA

STAMP: 220 SWIFT R-1492

FIT

D FLUSH WHEN
M IS 1.5295 $^{+.0002}_{-.0000}$

758 $^{+.0002}_{-.0000}$

B	.0002

20 $^{+.005}_{-.000}$

'A

/A

4

GENERAL NOTES

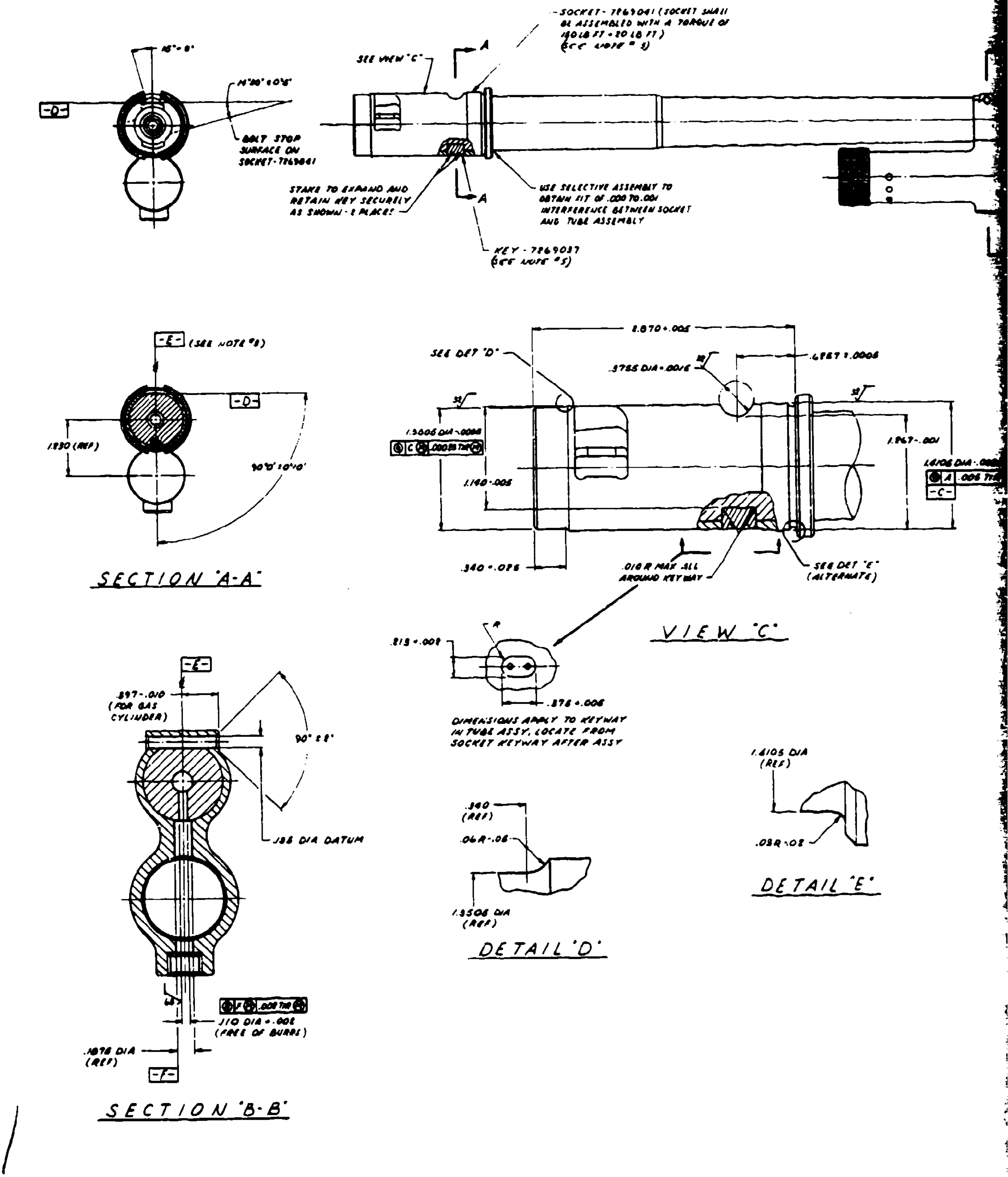
(UNLESS OTHERWISE SPECIFIED)

1. TOLERANCES : FRACTIONAL $\pm \frac{1}{64}$
   ANGULAR $\pm 1°$
2. FUNCTION : CHECK 1.5295 $^{+.0060}_{-.0000}$ DIM AT .335 DIA REF
3. MATL: D-2 TOOL STL HEAT TREAT TO R_c 58-62

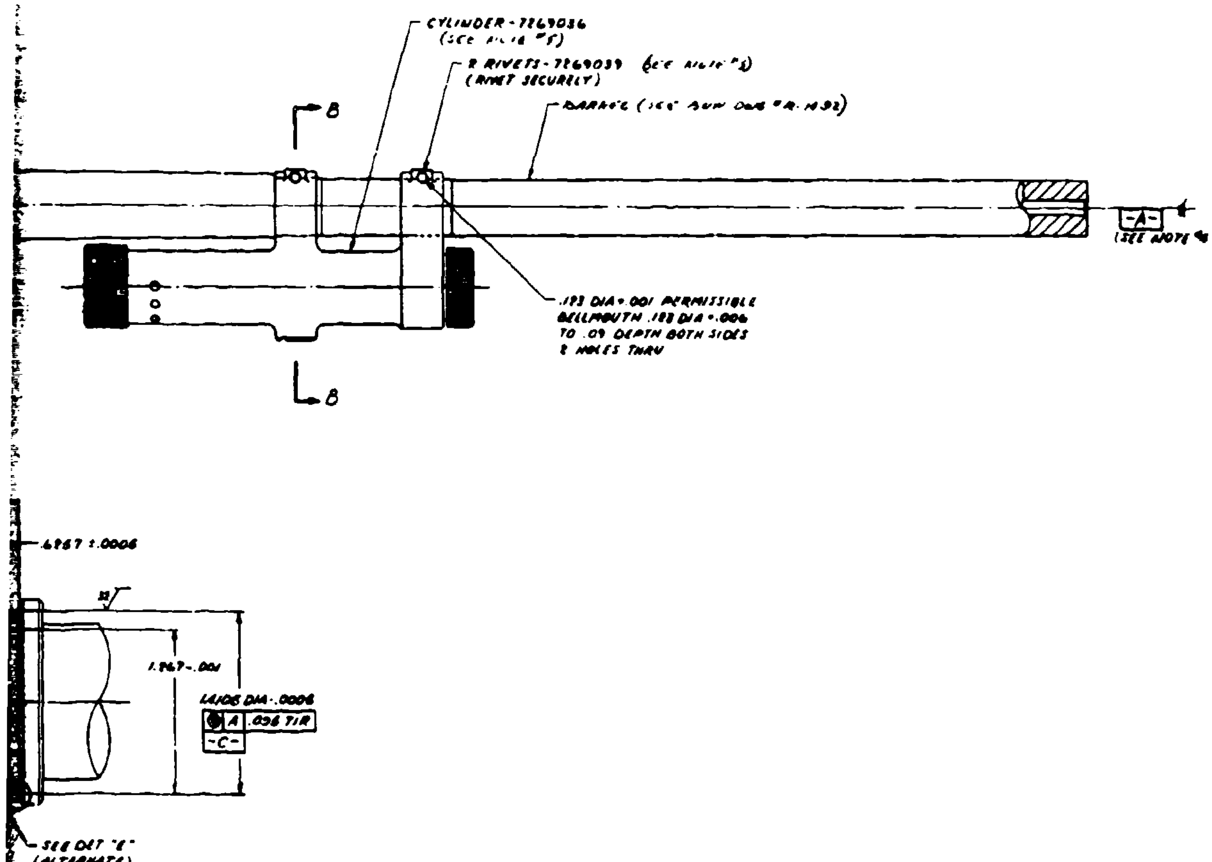
DWG NO. R-1926 REV 1

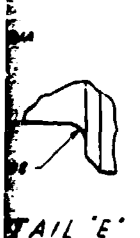
Figure I-7. Flush Pin Gage .220 Swift Chamber (Reference Drawing R-1492, Figure I-5. .220 Swift Barrel)

(The reverse of this page is blank)



SOCKET - 7269041 (SOCKET SHALL BE ASSEMBLED WITH A TORQUE OF 180 LB FT + 20 LB FT) (SEE NOTE # 5)
SEE VIEW "C"
A
-D-
BOLT STOP SURFACE ON SOCKET-7269041
STAKE TO EXPAND AND RETAIN KEY SECURELY AS SHOWN - 2 PLACES
USE SELECTIVE ASSEMBLY TO OBTAIN FIT OF .000 TO .001 INTERFERENCE BETWEEN SOCKET AND TUBE ASSEMBLY
KEY - 7269037 (SEE NOTE #5)
-E- (SEE NOTE #8)
-D-
1.830 (REF)
90°0' ± 0°10'
SECTION "A-A"
2.870 ± .005
SEE DET "D"
.3755 DIA ± .0015
.6857 ± .0005
1.3505 DIA - .0005
1.140 - .005
1.967 - .001
1.4105 DIA
-C-
.340 ± .025
.010 R MAX ALL AROUND KEYWAY
SEE DET "E" (ALTERNATE)
VIEW "C"
R
.813 ± .002
.375 ± .005
DIMENSIONS APPLY TO KEYWAY IN TUBE ASSY, LOCATE FROM SOCKET KEYWAY AFTER ASSY
-E-
.897 - .010 (FOR GAS CYLINDER)
90° ± 2°
.188 DIA DATUM
.110 DIA ± .002 (FREE OF BURRS)
.1875 DIA (REF)
-F-
SECTION "B-B"
.340 (REF)
.06 R - .06
1.3505 DIA (REF)
DETAIL "D"
1.4105 DIA (REF)
.03 R - .02
DETAIL "E"





NOTES:

1. FINISH √ EXCEPT AS NOTED.
2. ALL EDGES SHALL BE BROKEN .005±.010 UNLESS OTHERWISE SPECIFIED.
3. ℄ -B- IS ESTABLISHED BY ℄ -A- AND ℄ OF GAS CYLINDER BORE (.878 DIA, REF)
4. ℄ -A- IS ESTABLISHED BY ℄ OF BORE (.819 DIA, REF) AND ℄ OF SURFACE -B- AS SHOWN ON DWG R-1492.
5. PART NO. REFERS TO U.S. ARMY DRAWING NO. FOR THE PART (M-60 GUN)

DWG NO. R-1798 REV 0

Figure I-8. .220 Swift Barrel Assembly

(The reverse of this page is blank)

APPENDIX II

CERTIFICATION OF MATERIALS USED IN .220 SWIFT BARRELS

(The reverse of this page is blank)

ALLEN-FRY STEEL COMPANY

No. 98313

[illegible] ALCOA AVENUE – VERNON, CALIFORNIA [illegible]
TELEPHONE 58[illegible]-0611

CERTIFIED TEST REPORT

BATTELLE MO[illegible]
BOX 999
RICHLAND, WASHINGTON, 99352

SHIP TO
SAME
PHYSICAL SCIENCES BLDG 3000

ATTN: B. J. Seaver Buyer

SHIP TO SAME AS SOLD TO UNLESS OTHERWISE NOTED

Customer's order number	Order date	Shipped via	Partial shipment / Complete order	
BLS -7a7-BX /1511	8-25-70	U.S.AGT S	0 / 0	G 3

MILL SOURCE	COLOR	Size & Description
Universal-Cyclops	Green & White	4" RD CO A-286 Aged Hard AMS 5737C MBO 160-079A Except Ultrasonic

CHEMICAL ANALYSIS

HEAT NO.	C	MN	P	SU	SI	CR	NI	MO	VA	AL	SE	TI	CU	CB	COB	Boron
G-4973-K3	.057	1.26	.018	.006	.62	14.04	24.47	1.42	.23	.22		2.11				.0060

PHYSICAL PROPERTIES

Yield	108,500	105,000
Tensile	148,000	140,000
% Elong.	20.0	13.6
% Red of Area	25.5	17.1
Hardness BHN 302/311 (As Shipped)		
Grain Size: 5 & Finer		

OTHER

Combination Smooth Section Fracture

Life Hrs.	37.4	Stress P.S.I.	65,000
Temp °F.	1200	% Elong	5.0

SUBSCRIBED AND SWORN TO BEFORE ME
THIS 7th DAY OF May 19 69

NOTARY PUBLIC
IN AND FOR THE COUNTY OF LOS ANGELES, STATE OF CALIFORNIA
[illegible] 13, 1971

FORM TR 16

THE ALLEN FRY STEEL CO. CERTIFIES THAT THIS IS A TRUE COPY OF ORIGINAL TEST SHEET NOW ON FILE.

BY ____________
AUTHORIZED CERTIFICATION CLERK

Climax Molybdenum Company of Michigan
A Subsidiary of American Metal Climax, Inc.
Coldwater, Michigan

PRODUCT CERTIFICATION

Material Identification

Description	AMS Spec.	Heat No.
Climelt(R)Mo .5% Ti - 0.08%Zr 1 1/8 in. Dia. Wrought Bar	7819	TZM 8355

Chemical Composition — % (Check)

Mo*	W	Ti	Zr	C	O2	H2	N2	Fe	Ni
Balance		0.49	0.086	0.018	< 0.0002	< 0.0001	< 0.0001	< 0.004	< 0.001

Si									
< 0.003									

* By Difference

Structural Condition

Stress Relieved: 3/4 hr at 2350°F   Other:

Mechanical Properties

Ultimate — ksi	0.2% Yield — ksi	Elongation % in 4D	Hardness 10
116.6 - 120.2	100.0 - 101.6	21 - 27	272-279 DPH

Dimensional: ok   Penetrant Dye: ok   ~~Ultrasonic~~ ~~CMX-US-WB-1~~:   Surface Finish: ok

The undersigned, an authorized representative of Climax Molybdenum Co. of Michigan, certifies that the above information is correct and that all requirements of the above specifications have been complied with.

Date: 8-25-69

J. A. Hilbert

Battelle Northwest
PO No. - B1S-777 71509

Deliver to P. A. Ard   Req. B-92099 P.O. B1S-7E7-71509

CLIMAX MOLYBDENUM COMPANY OF MICHIGAN
A SUBSIDIARY OF AMERICAN METAL CLIMAX, INC.
COLDWATER, MICHIGAN

PRODUCT CERTIFICATION

MATERIAL IDENTIFICATION

Description	AMS Spec.	Heat No.
Climelt(R)Mo 0.5% Ti-Mo 1 1/8 in. Dia. Wrought Bar	AMS 7813	T 7894

CHEMICAL COMPOSITION — % (MAX)

Mo*	W	Ti	Zr	C	O2	H2	N2	Fe	Ni
Balance		0.52		0.018	0.0004	< 0.0001	0.0001	< 0.002	< 0.001

Si									
< 0.002									

* By Difference

STRUCTURAL CONDITION

Stress Relieved: 3/4 hr at 2100°F   Other:

MECHANICAL PROPERTIES

Ultimate — ksi	0.2% Yield — ksi	Elongation % in 4D	Hardness
112.1 - 113.6	94.7-96.0	10-13	262-270 DPN

Dimensional: ok   Penetrant Dye: ok   ~~Ultrasonic~~ ~~GWK-US-W3-1~~: [ ]   Surface Finish: ok

The undersigned, an authorized representative of Climax Molybdenum Co. of Michigan, certifies that the above information is correct and that all requirements of the above specifications have been complied with.

Date: 12-10-68   J. A. Hilbert

Battelle Northwest
PO No. - B1s-777 71509

UNIVERSAL-CYCLOPS SPECIALTY STEEL DIVISION

TERMS 30 DAYS NET ½% DISCOUNT ON $

B/L NO. R-04635

CUSTOMER ORDER NUMBER	CUST. ORDER DATE			MILL ENTRY DATE	DIST. / SLSMN.	SHIP DATE
BIS-7E7-71510	8/26/70			8/26/70	50 ¦ 305	8/27/70

INDEX NO.	CUST. CODE NO.	DUNS CODE	STATE/CNTY.	GOVT. RATING	MARKETING	PROD. OFF.	INVOICE NUMBER
T12486							BW7-6789

SOLD TO
BATTELLE NORTHWEST PACIFIC
PO BOX 999
RICHLAND, WASHINGTON 99352

SHIPPED TO
BATTELLE NORTHWEST PACIFIC
PHYSICAL SCIENCE BLDG. -3000 AREA
RICHLAND, WASHINGTON 99352
ATTN: MR. SEAVER

ROUTING ~~RAILROAD EXPRESS~~
[ ] COLL. [X] PPD. F.O.B. BRIDGEVILLE F/A BRIDGEVILLE

PACKING AND MARKING INSTRUCTIONS
PAPER WRAP
METAL TAG WITH CUST NO, SIZE, HEAT, TYPE, SPEC PATENT NO 2,740,250

INVOICE INSTR.	NO. INV.	PRICE B/O	OTHER	TEST REPORT INSTR.	ANAL.	PHYSICALS	NO. T/R	CERT.	NOTARIZED
							3		

STOCK CONTROL NO	QUAN. ORDERED PCS. OR WT.	SIZE AND DESCRIPTION	HEAT NO.	QUAN. SHIPPED NET WEIGHT	PRICE	AMOUNT
		UNITEMP L605 SOLUTION TREATED CENTERLESS GROUND BARS TO SPEC AMS-5759D				
53039	1 BAR APPROX 47 LBS	1-1/8" RD X 11 FT R/L ORDER COMPLETE	C10249			

TYPE	SPEC	SIZE	ORDER NO.
Unitemp L-605	AMS 5759D & GE B50T26 S7	1-1/8" rd.	T-12486

COND. & FINISH Centerless ground

HEAT NO.	C	MN	SI	S	P	CR	W	V	NI	MO	Co	Fe		
-10249	.070	1.37	.25	.010	.010	19.98	14.41		10.56		Bal	2.34		

TEST COND.	HARDNESS	YIELD	TENSILE	% EL.	% R.A.	BENDS	OTHER PROPERTIES
	BHN 202/217	.2% 57,500	128,000	61.5			

GR. SIZE	HARDENABILITY	TREATMENT	STRESS RUPTURE STRESS-PSI	TEMP.-°F.	TIME-HRS.	Elong
#2 & Finer			24,000	1500	24+	18.1%

REMARKS

B

I CERTIFY THAT THIS IS A TRUE AND CORRECT COPY OF THE TESTS SHOWN ON OUR LABORATORY RECORDS.

BY D. N. McElhaney
AUTHORIZED SIGNATURE

TEST REPORT

WAH CHANG ALBANY CORPORATION
A TELEDYNE COMPANY

Date	September 17, 1970
Date Shipped	September 17, 1970
*Quantity Shipped	1 pc. 21.6 lbs.
Production Order No	6545-1
Heat No	620031 Ta-10W

To Address: Battelle Northwest
P. O. Box 999
Richland, Washington 99352

*Total Shipped 38 - 3/16"

Attention of: Bud Seaver

In regard to your Purchase Order No: BIS-7E7-71513
Item No: 1
Description: Tantalum-10 Tungsten Rod
Dimensions: 1.062" dia. x 38" total
Specifications: AMS 7848 & Purchase Order

The Test Report Follows:

INGOT ANALYSIS

COMPOSITION IN PERCENT	Top	Bottom
W	10.2	10.7
Ta	BALANCE	
IMPURITIES IN PPM		
C	<30	<30
Cb	<50	<50
Fe	<40	<40
H	2.0	2.1
Mo	<20	<20
N	8	10
Ni	<20	<20
O	<50	60

PERCENT, RECRYSTALLIZATION
Material is 100% Recrystallized.

HARDNESS IN DPH
206

TENSILE TEST RESULTS @ ROOM TEMP.

Sample	Tensile Strength	Yield Strength (0.2% Offset)	Elongation In Percent
Long. #1	89,400	74,300	40.0
Long. #2	88,900	76,600	42.0

PRODUCT CHEMISTRY, PPM

C	40
O	70
N	10
H	1.1

Analysis Certified by [signature]
G. L. Prajeric
Quality Assurance Manager
kg.
351

WAH CHANG ALBANY CORPORATION
A TELEDYNE COMPANY
P O BOX 460 · ALBANY OREGON 97321 · TELEPHONE 503 [illegible]

TO ADDRESS	Battelle Northwest P. O. Box 999 Richland, Washington 99352	DATE	September 14, 1970
		DATE SHIPPED	September 10, 1970
		QUANTITY SHIPPED	2 pcs. 10.4 lbs.
		PRODUCTION ORDER NO	6546-2
		HEAT NO	650054 T-222

ATTENTION OF: Bud Seaver

IN REGARD TO YOUR PURCHASE ORDER NO BIS-7E7-71514
ITEM NO 1
DESCRIPTION T-222 Tantalum Alloy Rod
DIMENSIONS 1.0"-1.062" dia. x 9-1/2"
SPECIFICATIONS Chem. Per Purchase Order

THE TEST REPORT FOLLOWS:

INGOT ANALYSIS

COMPOSITION IN PERCENT	Top	Bottom
Hf	2.6	2.3
W	10.6	10.3
Ta	BALANCE	
IMPURITIES IN PPM		
C	155	125
Cb	640	590
Fe	20	20
H	1.9	1.9
N	6	7
Mo	30	30
Ni	<10	<10
O	90	90
V	<10	<10

INGOT HARDNESS IN BHN	
Range	277-302
Average	287

PRODUCT CHEMISTRY, PPM	
C	140
O	<50
N	10
H	<1

ASTM GRAIN SIZE
9.0

ANALYSIS CERTIFIED BY: G. L. Fredric
kz
C. L. Fredric
Quality Assurance Manager
9/1

APPENDIX III

FINAL INSPECTION REPORTS ON .220 SWIFT BARRELS

BATTELLE-NORTHWEST

INSPECTION REPORT FOR .220 SWIFT BARRELS

Drawings: R-1492 (Barrel) and R-1798 (Assembly)

REPORT NO. BAF-4

X - Indicates Dim. Within Tolerance

No. Code	Liner	Barrel
TM	TZM	A-286
MT	Mo-0.5Ti	A-286
L5	L605	A-286
TW	Ta-10W	A-286

Inspected by: J. O. Vining
Date: 9/8/71

LINE	INSPECTED CHARACTERISTIC BARREL	TM2-1	TM3-3	TM3-2	MT2-3	MT3-2	MT3-1	L53-1	L54-2	L54-3	TW3-3	TW2-3	TW1-1
		BARREL NUMBER											
1	Groove Diameter (0.224 + 0.001)	X (a)	X (a)	X (a)	X (a)	X (a)	X (a)	X	X	X	X	X	X
2	Groove Finish (32 RMS)	X	X	X	X	X	X	X	X	X	X	X (b)	X (b)
3	Bore Diameter (0.219 + 0.001)	X	X	X	X	X	X	X	X	X	X	X	X
4	Bore Finish (32 RMS)	X	X	X	X	X	X	X	X	X	X	X (b)	X (b)
5	Land Width (0.074 + 0.002)	X	X	X	X	X	X	X	X	X	X	X	X
6	Chamber Dia. at 1.9673 (0.226 + 0.002-001)					Controlled By Form Tool							
7	Chamber Dia. at 1.937 +020 (0.261 - 0.003)					Controlled By Form Tool							
8	Loc. of 0.261 + 0.003 dia. (1.937 + 0.020)	X	X	X	X	X	X	X	X	X	X	X	X
9	Loc. of Head Space (1.5295 + 0.0060)	X	X	X	X	X	X	X	X	X	X	X	X
10	Runout of Free Bore Dia. (0.003)	X	X	X	X	X	X	X	X	X	X	X	X
11	Diameter at 1.120 (0.4063 + 0.0050)					Controlled By Form Tool							
12	Diameter at 0.200 (0.4378 + 0.0050)					Controlled By Form Tool							
13	Runout of Large Chamber Taper (0.005)	X	X	X	X	X	X	X	X	X	X	X	X
14	1st Chamber Taper Finish (32 RMS)	X	X	X	X	X	X	X	X	X	X	X	X
15	2nd Chamber Taper Finish (32 RMS)	X	X	X	X	X	X	X	X	X	X	X	X
16	3rd Chamber Taper Finish (32 RMS)	X	X	X	X	X	X	X	X	X	X	X	X
17	4th Chamber Taper Finish (32 RMS)	X	X	X	X	X	X	X	X	X	X	X	X
18	5th Chamber Taper Finish (32 RMS)	X	X	X	X	X	X	X	X	X	X	X	X
19	5th Chamber Angle (1°30' ±30')	X	X	X	X	X	X	X	X	X	X	X	X
20	Length of Base Hub (115 -0.005)	X	X	X	X	X	X	X	X	X	X	X	X
21	Diameter of Base Hub (0.7895 -0.0050)	X	X	X	X	X	X	X	X	X	X	X	X
22	Chamfer on Base Hub (0.010 + 0.020x45°)	X	X	X	X	X	X	X	X	X	X	X	X
23	Int. Base Chamfer Angle (120°)	X	X	X	X	X	X	X	X	X	X	X	X
24	Int. Base Chamfer Angle Finish (63 RMS)	X	X	X	X	X	X	X	X	X	X	X	X
25	Ext. Th'd Chamfer Dia. (1.030 -0.015)	X	X	X	X	X	X	X	X	X	X	X	X
26	Base Hub R(015 -0.010)	X	X	X	X	X	X	X	X	X	X	X	X
27	1-1/8 - 16 UN Ext. Th'd	X	X	X	X	X	X	X	X	X	X	X	X

INSPECTION REPORT FOR .220 SWIFT BARRELS (Continued)

REPORT NO. BAF-4

Inspected by: J. O. Vining
Date: 9/8/71

LINE	INSPECTED CHARACTERISTIC	BARREL NUMBER											
	BARREL (Continued)	TM2-1	TM3-3	TM3-2	MT2-3	MT3-2	MT3-1	L53-1	L54-2	L54-3	TW3-3	TW -3	TW1-1
28	0.880 Min Fu-1 Th'd Length	X	X	X	X	X	X	X	X	X	X	X	X
29	Th'd Length (1.000 + 0.030)	X	X	X	X	X	X	X	X	X	X	X	X
30	Loc. of 1.193 -0.003 dia. 1.750 - 0.030)	X	X	X	X	X	X	X	X	X	X	X	X
31	Diameter (1.193 -0.003)	X	X	X	X	X	X	X	X	X	X	X	X
32	Runout of 1.193 diameter (0.002)	X	X	X	X	X	X	X	X	X	X	X	X
33	Length of 1.193 diameter (0.250 min)	X	X	X	X	X	X	X	X	X	X	X	X
34	Depth of U'cut Behind 1.193 dia. (0.001 + 0.002)	X	X	X	X	X	X	X	X	X	X	X	X
35	Finish on Surface Behind 1.193 dia. (32 RMS)	X	X	X	X	X	X	X	X	X	X	X	X
36	Large OD (1.197 -0.007)	X	X	X	X	X	X	X	X	X	X	X	X
37	OD Fwd of 1st Taper (1.100 -0.010)	X	X	X	X	X	X	X	X	X	X	X	X
38	Length of 1st Taper (0.125 ± 0.005)	X	X	X	X	X	X	X	X	X	X	X	X
39	Loc. of 1st Taper (6.875 ± 0.005)	X	X	X	X	X	X	X	X	X	X	X	X
40	Loc. of Ext Groove (13.545 -0.012)	X	X	X	X	X	X	X	X	X	X	X	X
41	Dia. at 13.545 -0.012 Length (0.960 -010)	X	X	X	X	X	X	X	X	X	X	X	X
42	Dia. of Ext Groove (0.862 -0.006)	X	X	X	X	X	X	X	X	X	X	X	X
43	Length of Ext Groove (090 max)	X	X	X	X	X	X	X	X	X	X	X	X
44	Radii In Ext Groove (0.005 + 0.010)	X	X	X	X	X	X	X	X	X	X	X	X
45	Dia. Fwd of Ext Groove (0.8765 -0.0005)	X	X	X	X	X	X	X	X	X	X	X	X
46	Finish on Dia Fwd of Ext Groove (63 RMS)	X	X	X	X	X	X	X	X	X	X	X	X
47	Loc. of 2nd Ext Taper (14.220 -0.060)	X	X	X	X	X	X	X	X	X	X	X	X
48	Length of 2nd Ext Taper (0.125 max)	X	X	X	X	X	X	X	X	X	X	X	X
49	Dia. Fwd of 2nd Ext Taper (0.8565 -0.0005)	X	X	X	X	X	X	X	X	X	X	X	X
50	Loc. of 3rd Ext Taper (16.180 -0.060)	X	X	X	X	X	X	X	X	X	X	X	X
51	Length of 3rd Ext Taper (0.125 max)	X	X	X	X	X	X	X	X	X	X	X	X
52	Dia. Fwd of 3rd Ext Taper (0.840 -0.010)	X	X	X	X	X	X	X	X	X	X	X	X
53	Runout of 0.840 diameter (0.005)	X	X	X	X	X	X	X	X	X	X	X	X
54	Muzzle End to Bore (0.005)	X	X	X	X	X	X	X	X	X	X	X	X
55	Ext. Chamfer Muzzle End (0.010 + 0.020x45°)	X	X	X	X	X	X	X	X	X	X	X	X
56	Int. Chamfer Muzzle End (0.010 + 0.010x45°)	X	X	X	X	X	X	X	X	X	X	X	X
57	Int. Chamfer Muzzle End Finish (63 RMS)	X	X	X	X	X	X	X	X	X	X	X	X
58	Int. Chamfer Muzzle End Runout (0.005)	X	X	X	X	X	X	X	X	X	X	X	X
59	Overall Length (26.000 - 0.100)	X	X	X	X	X	X	X	X	X	X	X	X
60	Straightness	X	X	X	X	X	X	X	X	X	X	X	X

INSPECTION REPORT FOR .220 SWIFT BARRELS (Continued)

REPORT NO. BAF-4

Inspected by: J. O. Vining
Date: 10/11/77

LINE	INSPECTED CHARACTERISTIC	BARREL NUMBER											
		TM2-1	TM3-3	TM3-2	MT2-3	MT3-2	MT3-1	L53-1	L54-2	L54-3	TW3-3	TW2-3	TW1-1
	ASSEMBLY												
1	Presence of Gas Cylinder	X	X	X	X	X	X	X	X	X	X	X	X
2	Presence of Breech Socket	X	X	X	X	X	X	X	X	X	X	X	X
3	Presence of Gas Cylinder Pins	X	X	X	X	X	X	X	X	X	X	X	X
4	Presence of Socket Key	X	X	X	X	X	X	X	X	X	X	X	X
5	Socket Assembly Torque (150 + 20 Ftlb)	X	X	X	X	X	X	X	X	X	X	X	X
6	Relationship of Gas Cyl to Soc (90° ± 0°10")	X	X	X	X	X	X	X	X	X	X	X	X
7	Gas Cyl Barrel Hole (0.110 + 0.002 dia.)	X	X	X	X	X	X	X	X	X	X	X	X
8	Socket Base Dia. (1.3505 -0.0005 dia.)	X	X	X	X	X	X	X	X	X	X	X	X
9	Socket Fwd Dia. (1.4105 -0.0005 dia.)	X	X	X	X	X	X	X	X	X	X	X	X
10	Socket Relief Slot (0.3755 + 0.0015 dia.)	X	X	X	X	X	X	X	X	X	X	X	X
11	Loc. of Soc Relief Slot (0.6257 ± 0.0005)	X	X	X	X	X	X	X	X	X	X	X	X
12	Bolt Stop Surface (14°30' ± 0°15')	X	X	X	X	X	X	X	X	X	X	X	X

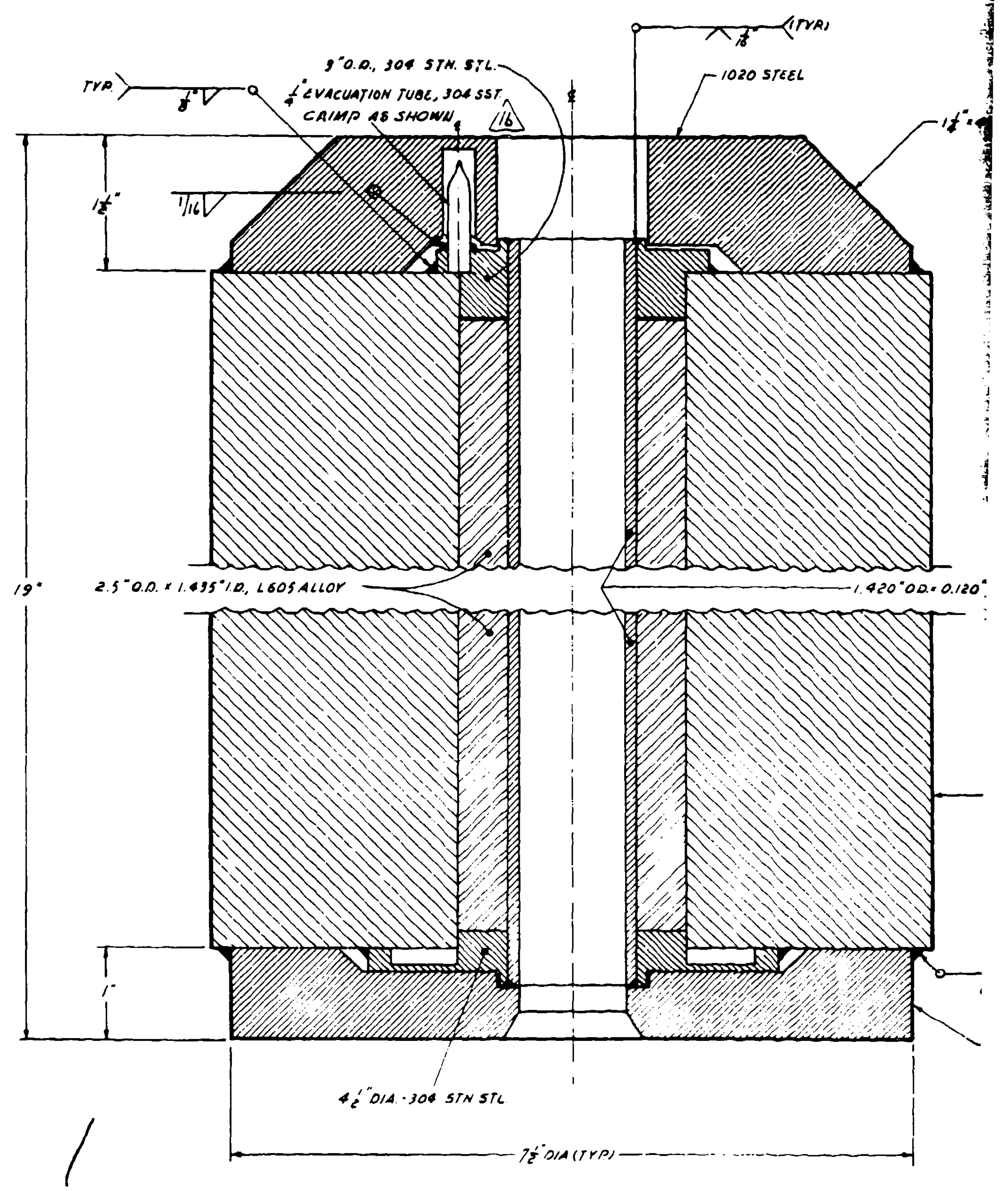
(a) Groove and Bore Diameter OK to -0.0002 after Machining
(b) Galled Rifling in Spots

(The reverse of this page is blank)

APPENDIX IV

25MM BARREL FABRICATION DRAWINGS

(The reverse of this page is blank)



9" O.D., 304 STN. STL.
TYP.
1/8"
1/4" EVACUATION TUBE, 304 SST.
CRIMP AS SHOWN
16
1020 STEEL
(TYP)
1/16"
1/16
1 1/2"
19"
2.5" O.D. x 1.435" I.D., L605 ALLOY
1.420" O.D. x 0.120"
1"
4 1/2" DIA. - 304 STN STL
7 1/2" DIA (TYP)

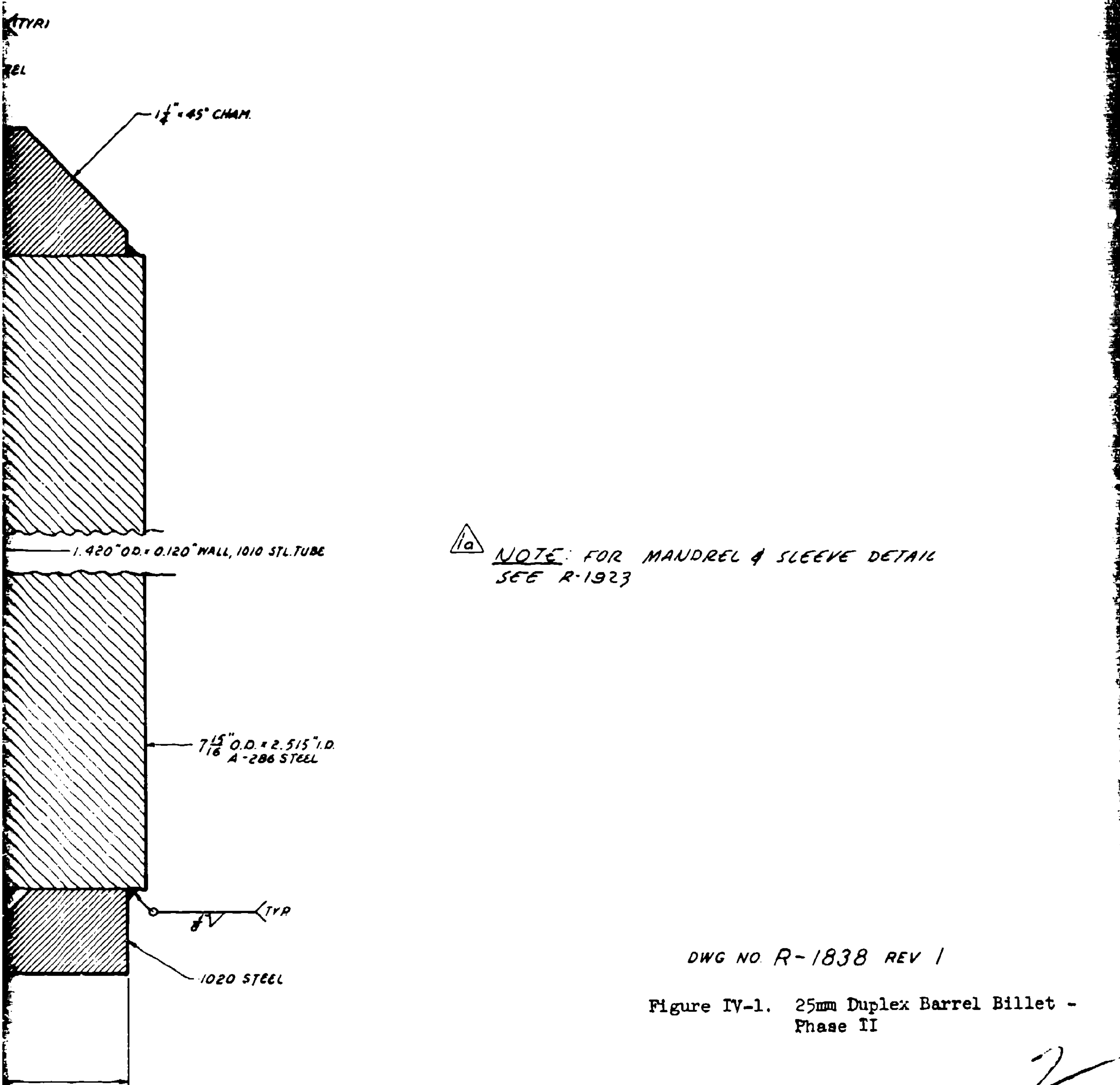
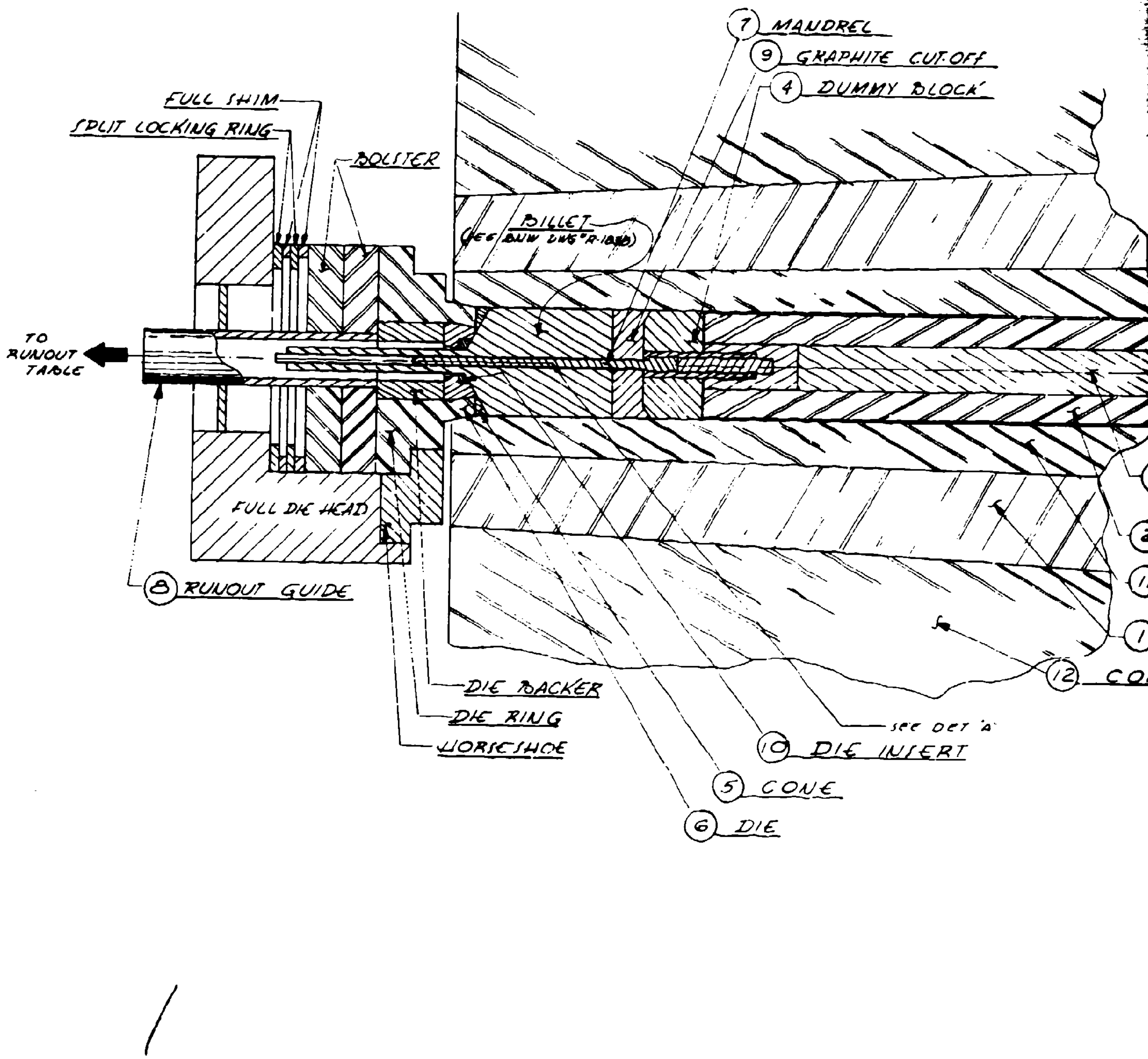
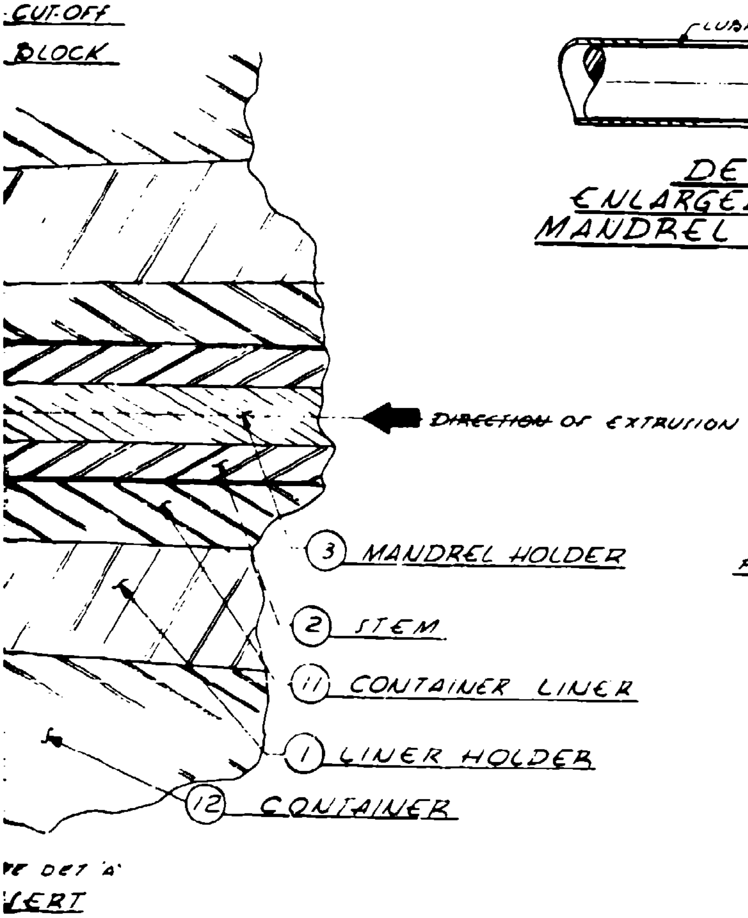


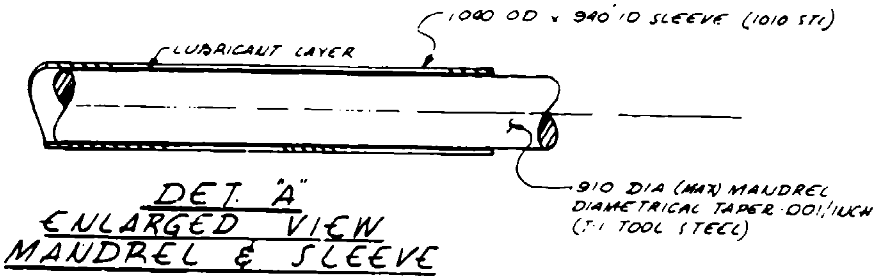
Figure IV-1. 25mm Duplex Barrel Billet - Phase II

(The reverse of this page is blank)



7 MANDREL
9 GRAPHITE CUT-OFF
4 DUMMY BLOCK
FULL SHIM
SPLIT LOCKING RING
BOLSTER
BILLET
(SEE BNW DWG R-1850)
TO RUNOUT TABLE
FULL DIE HEAD
8 RUNOUT GUIDE
DIE BACKER
DIE RING
HORSESHOE
SEE DET 'A'
10 DIE INSERT
5 CONE
6 DIE
12 CO





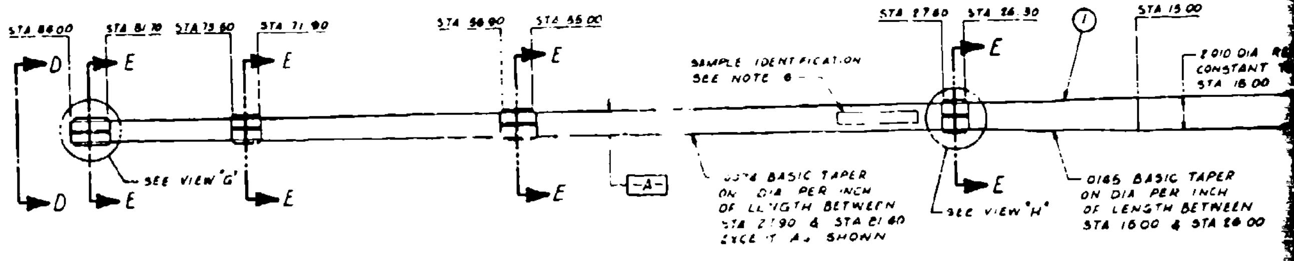
PARTS FUNCTION

PART NO.	FUNCTION
1	CONTAINS RADIAL FORCE
2	TRANSMITS FORCE TO BILLET
3	HOLDS MANDREL IN STEM
4	SEALS OFF REAR OF EXTRUSION
5	DIRECTS EXTRUSION FLOW
6	SHAPES EXTRUSION OD
7	SHAPES EXTRUSION ID
8	DIRECTS EXTRUSION TOWARDS TABLE
9	CLEARS BILLET MATERIAL FROM DIE
10	WITHSTANDS HIGH EXTRUSION TEMPERATURES
11	CONTAINS RADIAL FORCE
12	HOLDS LINER & LINER HOLDER ASSY

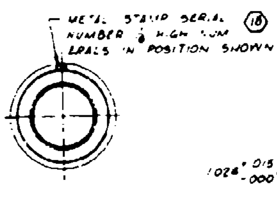
DWG NO R-1923 REV 0

Figure IV-2. 25mm Duplex Barrel Billet Extrusion Assembly - 3850 Ton Press

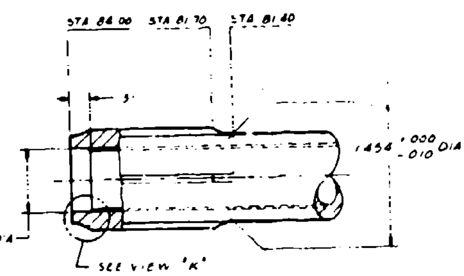
(The reverse of this page is blank)



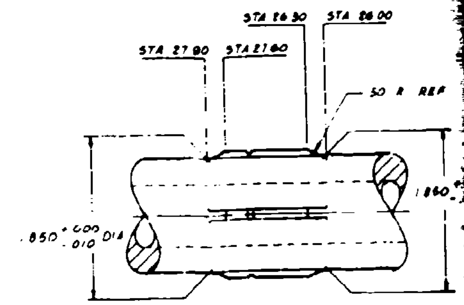
ASSEMBLY
SCALE 1/4



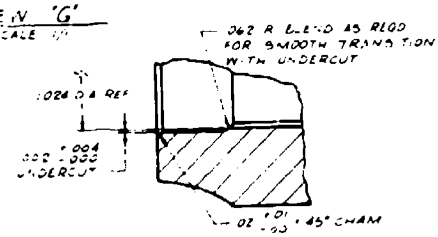
VIEW 'D-D'
SCALE 1/1



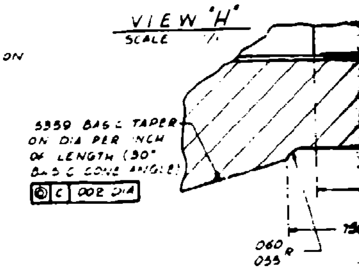
VIEW 'G'
SCALE 1/1



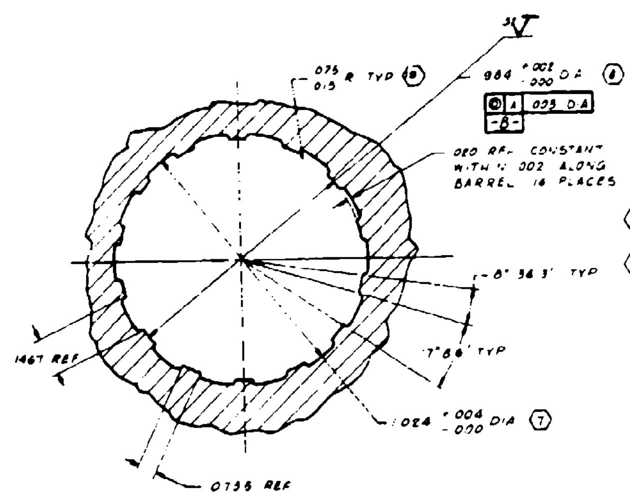
VIEW 'H'
SCALE 1/1



VIEW 'K'
SCALE 4/1

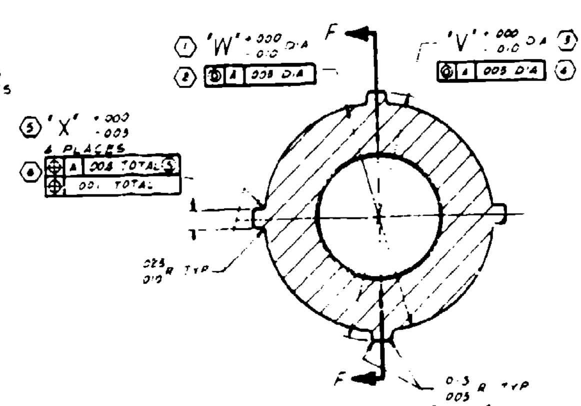


VIEW

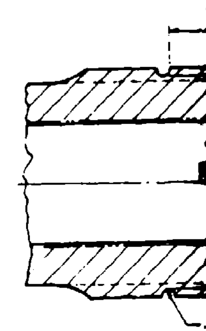


RIFLING DETAIL SCALE 4/1

STATION INCHES	ROTATION DEGREES	ROTATION MINUTES	STATION INCHES	ROTATION DEGREES	ROTATION MINUTES	STATION INCHES	ROTATION DEGREES	ROTATION MINUTES
0	0	0	30	21	38.1	60	449	20.0
2	0	00	32	38	43.4	62	476	43.9
4	0	48	34	56	20.5	64	504	29
6		32.5	36	74	4.5	66	532	46.0
8	4	18.2	38	88	49	68	56	4.8
10	6	30.5	40	2.3	40.2	70	59	0.9
12	6	13.1	42	284	4.6	72	62	5.6
14	7	35.3	44	235	31.3	74	65	34.5
16	30	5.2	46	277	29.1	76	689	7.9
18	40	2.6	48	300	62	78	7.4	55.4
20	3	20.3	50	323	27.1	80	74	8
22	45	33	52	347	13.0	82	779	50.8
24	76	46.0	54	372	2.4	83	8.5	2.2
26	90	00.6	56	397	70			
28	.06	4	58	423	00			

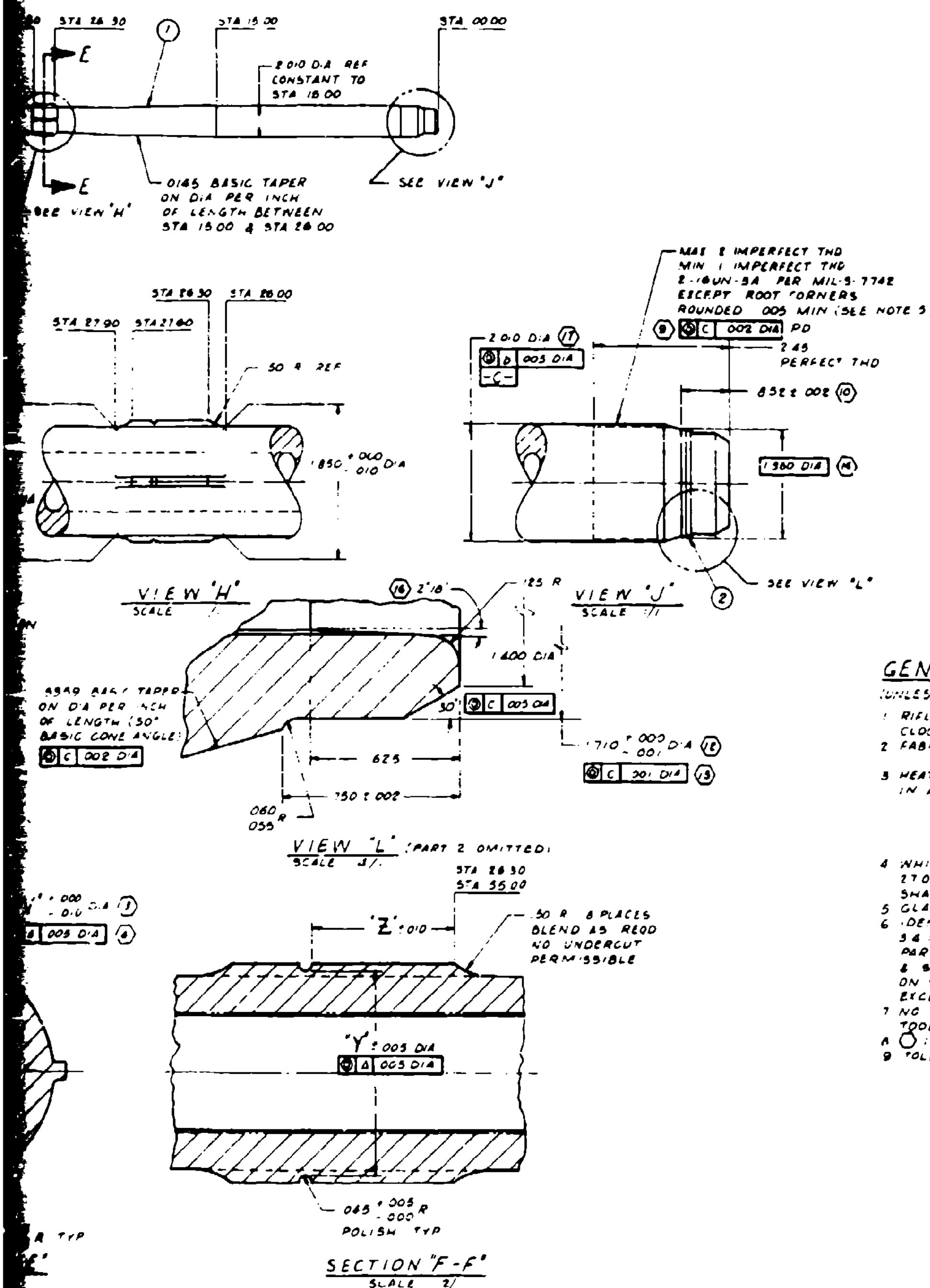


SECTION 'E-E'
SCALE 2/1



STATION	'V'	'W'	'X'	'Y'
26.30 TO 27.80	2.050	1.850	.133	[illegible]
55.00 TO 56.90	.850	.650	.45	[illegible]
[illegible]90 TO 73.50	.750	.550	.137	NA
8[illegible] TO 84.00	.650	.450	.129	NA

SPLINES SHALL BE IN LINE WITHIN 0° ADJACENT SPLINES ONLY NOT CUMULATIVE



STATION	'V'	'W'	'X'	'Y'	'Z'
[illegible]0 TO 27 80	2 050	1 850	155	960	900
[illegible]00 TO 58 90	850	650	165	700	1 200
[illegible] TO 76 50	750	550	137	NA	NA
[illegible]0 TO 84 00	650	450	129	NA	NA

SPLINES SHALL BE IN LINE WITHIN 0° ADJACENT SPLINES ONLY NOT CUMULATIVE

GENERAL NOTES

(UNLESS OTHERWISE SPECIFIED)

1 RIFLING ROTATION GIVEN BY TABLE DIRECTION CLOCKWISE
2 FABRICATION PROCEDURE PER EPS-47940
3 HEAT TREATMENT AGE AT 1325°F 16 HOURS IN AIR, AIR COOL TO ROOM TEMP
4 WHILE FREELY SUPPORTED AT STATIONS 2 0, 27 0 55 5, 72 0 & 83 0, FINISHED BARREL SHALL BE STRAIGHT WITHIN 010 TIR
5 GLASS BEAD PEEN THD PER MIL-S-13165
6 IDENTIFY PER MIL-STD-130 (AMPE 12.0 PARA 5 4 10 0) IDENTIFICATION SHALL CONSIST OF PART NO & REVISION LTR, SHOP ORDER NO & SERIAL NO IF MORE THAN ONE PART IS MADE ON SAME SHOP ORDER (DO NOT METAL STAMP EXCEPT AS SHOWN IN VIEW "D-D")
7 NO BURRS SCRATCHES NICKS, HAMMER OR TOOLING MARKS PERMITTED
8 ⬡ INDICATES CRITICAL DIM INSPECT & RECORD
9 TOLERANCES
DECIMAL XX ± 03 ANGULAR ± 0°30'
XXX ± 010

DWG NO 47408 REV M

Figure IV-3. Barrel Engineer Model Gun

(The reverse of this page is blank)

APPENDIX V

CERTIFICATION OF MATERIALS USED IN 25MM BARRELS

(The reverse of this page is blank)

UNIVERSAL-CYCLOPS SPECIALTY STEEL DIVISION

• TERMS: 30 DAYS NET · ½% DISCOUNT ON $ R1251

CUSTOMER ORDER NUMBER	CUST. ORDER DATE	STA. CTL. NO.	S.T.C.	MILL ENTRY DATE	DIST. SLSMN.	SHPG. & INV. DATE
B2F-777-72130	10/25/71			10/25/71	50 305	10/27/71

ORDER NO.	CUST. CODE NO.	BUS. CODE	STATE/CNTY.	GOVT. RATING	MARKET CODE	PROD. OFF.	INVOICE NUMBER
T13076							NW7-7031

SOLD TO BATTELLE NORTHWEST
• BATTELLE MEMORIAL INSTITUTE
PACIFIC NORTHWEST LABORATORIES
P O BOX 999
RICHLAND, WASHINGTON 99352

SHIPPED TO BATTELLE NORTHWEST
BATTELLE MEMORIAL INSTITUTE
6TH ST. WHSE.
RICHLAND, WASHINGTON 99352

ROUTING TRUCK/RUSH/
COLL. PPD. F.O.B. BRIDGEVILLE P/C PITTSBURGH

PACKING AND MARKING INSTRUCTIONS
BUNDLE AND PAPER WRAP
METAL TAG WITH CUST NO., SIZE, HEAT, TYPE, SPEC.

INVOICE INSTR.	NO. INV.	PRICE O/D	OTHER	TEST REPORT INSTR.	ANAL.	PHYSICALS	NO. T/R	CERT.	NOTARIZED
			T/R ATTN: W. J. LIECHTY/SOLD TO/				3		

STOCK CONTROL NO.	QUAN. ORDERED PCS. OR WT.	SIZE AND DESCRIPTION	HEAT NO.	QUAN. SHIPPED NET WEIGHT	PRICE	AMOUNT
		UNITEMP L605 SOLUTION TREATED CENTERLESS GROUND BARS TO SPEC. AMS-5759D	C10328			
53058	ITEM 1 220 LBS.	2-1/2" RD X 11 FT R/L ORDER COMPLETE				

0694 789

TYPE	SPEC.	SIZE	ORDER NO.
Unitemp L-605	AMS 5759D & G.E.B50T26-S7	2-1/2" rd.	T-13076

COND. & FINISH Centerless Ground Bars

HEAT NO.	C	MN	SI	S	P	CR	W	V	NI	MO	Co	Fe		
C-10328	.068	1.53	.36	.010	.009	19.66	14.79		10.10		Bal.	2.58		

TEST COND.	HARDNESS	YIELD	TENSILE	% EL.	% R.A.	BENDS	OTHER PROPERTIES
	BHN 202/212	.2% 64,600	131,000	57.2			

GR. SIZE	HARDENABILITY	TREATMENT	STRESS RUPTURE			
			STRESS-PSI	TEMP.-°F.	TIME-HRS.	Elong.
#2 & finer			24,000	1500	75.0	16.9%

REMARKS:

B

I CERTIFY THAT THIS IS A TRUE AND CORRECT COPY OF THE TESTS SHOWN ON OUR LABORATORY RECORDS.

BY D. N. McElhaney
AUTHORIZED SIGNATURE

Crucible
SP 425.501R 1/70

Colt Industries — Crucible Specialty Metals Division
Box 977, Syracuse, N. Y. 13201

CERTIFICATE OF TEST

SOLD TO	SHIPPED TO	DATE
Battelle Northwest Pacific Northwest Laboratories P O Box 999 Richland, Wash. 99352	Same 6th Street Whse. Hanford, Wash.	2/29/72

CUSTOMER ORDER NO.	B2P-777-72104	MILL ORDER NO.	4-77-20001-2	DISTRICT	Portland
INVOICE NO.	1005	SHIPPED FROM	Syracuse	DATE OF SHIPMENT	2/25/72

DESCRIPTION OF MATERIAL

A-286 FGD RT SOLUTION HEAT TRTD AMS-5736E

Refer to Executive Order 11613

ITEM NO.	SIZE	QUANTITY	HEAT NO.	YIELD PSI .2%	TENSILE PSI	% ELONG IN.	% RED AREA	HARDNESS	IMPACT
1 Pcs	8" Rd.	245#	C33237-2					BHN 163	

Physicals after 1800 deg 1 hr water - 1325 deg 16 hrs air:

YIELD PSI	TENSILE PSI	% ELONG	% RED AREA	HARDNESS
113,500	159,500	18.0%	33.5%	BHN 311

Combination Stress Rupture 1200 deg 70,000 psi 67.8 Hrs 13.4% Elg.

Grain Size #6

CHEMICAL PROPERTIES

ITEM NO.	HEAT NO.	C	MN	P	S	SI	NI	CR	V	W	MO	Ti	Boron	Al
	C33237	.06	1.48	.020	.005	.94	24.84	15.08	.37		1.23	2.29	.005	.18

THE TEST RESULTS SHOWN IN THIS REPORT ARE CORRECT TO THE BEST OF OUR KNOWLEDGE AND BELIEF.

COLT INDUSTRIES CRUCIBLE INC.

CERTIFIED BY ________ REPRESENTATIVE

APPENDIX VI

FINAL INSPECTION REPORTS ON 25MM BARRELS

(The reverse of this page is blank)

GAU-7/A BARRELS

P/N 47408 N

Dimensions	S/N Number 2	S/N Number 3	S/N Number 1	
1.710 +0.000 -0.001	1.710	1.710	1.710	
2.010 Diameter Constant	2.0185	2.0165/2.018	2.012/2.014	
[A]2.050 +0.000 -0.010	2.048	2.0485/2.0487	2.0475	
[A]1.850 +0.000 -0.010	1.8476	1.850	1.8495	
[A]1.750 +0.000 -0.010	1.7497	1.7482	1.749	
[A]1.650 +0.000 -0.010	1.658	1.659	1.6498	This dimension out on all barrels
[B]1.850 +0.000 -0.010	1.843/1.845	1.849	1.847/1.8475	
[B]1.650 +0.000 -0.010	1.643/1.644	1.6455/1.6485	1.644/1.6455	
[B]1.550 +0.000 -0.010	1.5525	1.5465	1.541/1.547	
[B]1.450 +0.000 -0.010	1.452	1.445/1.448	1.447	
[C]0.155 +0.000 -0.003	0.154	0.153	0.152/0.154	
[C]0.145 +0.000 -0.003	0.143	0.143	0.143	
[C]0.137 +0.000 -0.003	0.1355/0.136	0.135/0.136	0.134/0.135	
[C]0.129 +0.000 -0.003	0.126/0.128	0.1270.128	0.1255/0.128	
[D]1.960 + -0.005	1.971	1.975	1.975	This dimension out on all barrels
[D]1.760 + -0.005	1.774	1.775	1.746/1.749	This dimension out on all barrels
[E]0.900 + -0.010	0.910	0.910	0.910	
[E]1.200 + -0.010	1.198	1.205	1.202	

GAU-7/A BARRELS

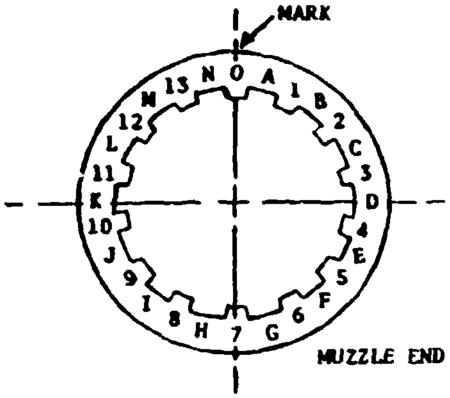
P/N 47408 N

(Concluded)

Dimensions	S/N Number 2	Number 3	Number 1
1.400 Diameter	1.403	1.398	1.401
0.045 +0.005 Rad. Tup.	OK	OK	OK
30° ± 0° 30'	OK	OK	OK
0.750 ± 0.002	0.750	0.750	0.750
0.055/0.060 Rad	0.06	0.06	0.06
0.852 ± 0.002	0.852	0.850	0.851
1.860 Diameter BSC.	1.860	1.860	1.860
2.45 PECT. TADS.	2.45	2.45	2.45
0.984 +0.002 -0.000 Diameter	Will Not Accept		0.98317 Pin
All · and + to OD	OK	OK	OK
Basic Tapers	OK	OK	OK
2 inches -16 3A THDS	Accept gage	Accept gage	Accept gage
Weight	39.5	39.5	39.5

AIR GAGE DATA SHEET

DEVELOPMENT BARRELS
LAND AND GROOVE DIAMETERS



Date: November 14, 1972

Barrel Type: GAU-7/A

Barrel P/N: 47408 H S/N: 1

Test No. ____________

Rounds Fired: ____________
(Since Last Inspection)

____
(Cumulative)

Ammunition Type: ____________

Lot: ____________

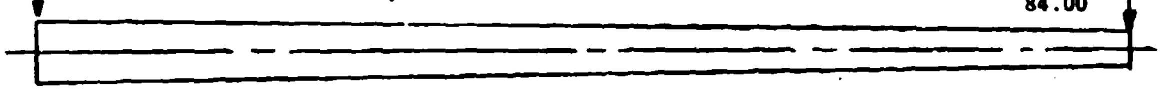
Engineer: ____________

Drawing Dimensions:

Land Diameter $0.984^{+0.002}_{-0.000}$

Groove Diameter $1.024^{+0.004}_{-0.000}$

STA 00.00 STA 84.00



BREECH MUZZLE

DIAMETER AT BARREL STATION

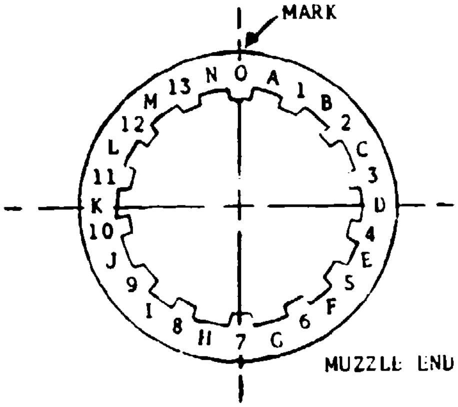
Land / Groove	0.25	0.70	6.00	12.00	24.00	48.00	72.00	muzzle	
0-7	0.984	0.984	0.984	0.984	0.984	0.984	0.984		
A-H	1.026	1.026	1.026	1.026	1.026	1.027	1.027		
1-8	0.984	0.984	0.984	0.984	0.984	0.984	0.984		
B-I	1.026	1.026	1.026	1.026	1.026	1.027	1.026		
2-9	0.984	0.984	0.984	0.984	0.984	0.984	0.984		
C-J	1.026	1.026	1.027	1.027	1.027	1.027	1.027		
3-10	0.984	0.984	0.984	0.984	0.984	0.984	0.984		
D-K	1.026	1.026	1.026	1.026	1.026	1.027	1.027		
4-11	0.984	0.984	0.984	0.984	0.984	0.984	0.984		
E-L	1.026	1.026	1.026	1.026	1.026	1.026	1.026		
5-12	0.984	0.984	0.984	0.984	0.984	0.984	0.984		
F-M	1.026	1.026	1.025	1.026	1.026	1.025	1.026		
6-13	0.984	0.984	0.984	0.984	0.984	0.983	0.983		
G-N	1.026	1.026	1.026	1.026	1.025	1.026	1.026		

*Reworked 11/14/72 Accepts 9840 Gage

REMARKS INSP 11/14/72

AIR GAGE DATA SHEET

DEVELOPMENT BARRELS
LAND AND GROOVE DIAMETERS



Date: November 14, 1972

Barrel Type: GAU-7/A

Barrel P/N: 47408 N S/N: 2

Test No.

Rounds Fired:
(Since Last Inspection)

(Cumulative)

Ammunition Type:

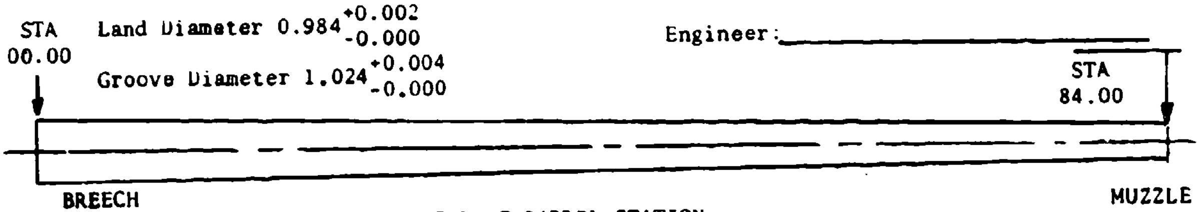
Lot:

Engineer:

Drawing Dimensions:

Land Diameter $0.984^{+0.002}_{-0.000}$

Groove Diameter $1.024^{+0.004}_{-0.000}$



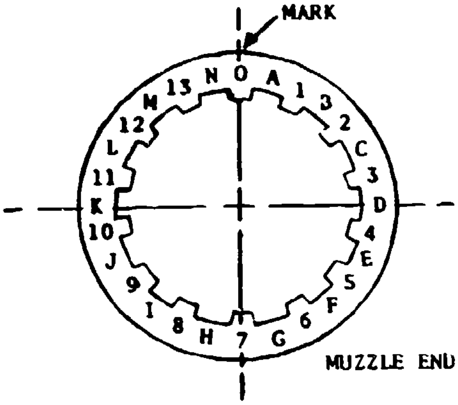
DIAMETER AT BARREL STATION

Land / Groove	0.25	0.70	6.00	12.00	24.00	48.00	72.00	muzzle	
0-7	0.984	0.984	0.984	0.984	0.984	0.984	0.984		
A-H	1.027	1.027	1.027	1.027	1.027	1.027	1.027		
1-8	0.984	0.984	0.984	0.984	0.984	0.984	0.984		
B-I	1.026	1.026	1.026	1.026	1.026	1.027	1.027		
2-9	0.984	0.984	0.984	0.984	0.984	0.984	0.984		
C-J	1.086	1.086	1.027	1.027	1.026	1.026	1.026		
3-10	0.984	0.984	0.984	0.984	0.984	0.985	0.984		
D-K	1.025	1.025	1.026	1.087	1.026	1.026	1.027		
4-11	0.984	0.984	0.984	0.984	0.984	0.984	0.984		
E-L	1.026	1.026	1.026	1.026	1.026	1.027	1.027		
5-12	0.984	0.984	0.984	0.984	0.984	0.984	0.984		
F-M	1.027	1.027	1.027	1.027	1.027	1.027	1.027		
6-13	0.984	0.984	0.984	0.984	0.984	0.984	0.984		
G-N	1.027	1.027	1.027	1.027	1.027	1.026	1.026		

REMARKS INSP 11/14/72

AIR GAGE DATA SHEET

DEVELOPMENT BARRELS
LAND AND GROOVE DIAMETERS



Date: November 14, 1972

Barrel Type: GAU-7/A

Barrel P/N: 47408 N S/N: 3

Test No.

Rounds Fired: ____ (Since Last Inspection)

____ (Cumulative)

Ammunition Type:

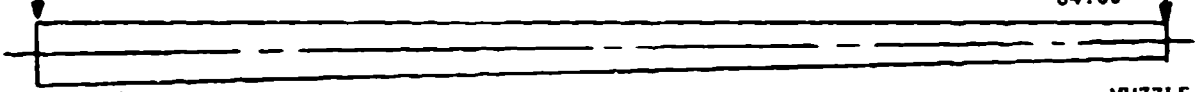
Lot:

Engineer:

Drawing Dimensions:

Land Diameter $0.984^{+0.002}_{-0.000}$

Groove Diameter $1.024^{+0.004}_{-0.000}$



DIAMETER AT BARREL STATION

Land / Groove	0.25	0.70	6.00	12.00	24.00	48.00	72.00	muzzle	
0-7	0.984	0.984	0.984	0.984	0.984	0.984	0.984		
A-H	1.026	1.026	1.026	1.027	1.026	1.027	1.027		
1-8	0.984	0.984	0.984	0.984	0.984	0.984	0.984		
B-i	1.026	1.026	1.026	1.026	1.027	1.026	1.026		
2-9	0.984	0.984	0.984	0.984	0.984	0.984	0.984		
C-J	1.026	1.026	1.027	1.027	1.027	1.027	1.027		
3-10	0.984	0.984	0.984	0.984	0.984	0.984	0.984		
D-K	1.027	1.027	1.027	1.027	1.027	1.027	1.027		
4-11	0.984	0.984	0.984	0.984	0.984	0.984	0.984		
E-L	1.026	1.026	1.026	1.026	1.026	1.026	1.026		
5-12	0.984	0.984	0.984	0.984	0.984	0.984	0.984		
F-M	1.027	1.027	1.027	1.027	1.027	1.027	1.026		
6-13	0.984	0.984	0.984	0.984	0.984	0.984	0.984		
G-N	1.027	1.027	1.027	1.027	1.027	1.027	1.027		

REMARKS INSP 11/14/72

(The reverse of this page is blank)

UNCLASSIFIED

Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Pacific Northwest Laboratory, Division of Battelle Memorial Institute Richland, Washington 99352	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3. REPORT TITLE
RESEARCH AND DEVELOPMENT ON COEXTRUSION OF BIMETALLIC .220 SWIFT AND 25MM GUN BARRELS

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)
Final Report - July 1970 to November 1972

5. AUTHOR(S) (First name, middle initial, last name)
Philip A. Ard

6. REPORT DATE December 1972	7a. TOTAL NO. OF PAGES 98	7b. NO. OF REFS
8a. CONTRACT OR GRANT NO. F08635-71-C-0013 b. PROJECT NO. 670A c. Task No. 02 d. Work Unit No. 022	9a. ORIGINATOR'S REPORT NUMBER(S) 211B00386/211B00840 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report) AFATL-TR-72-232	

10. DISTRIBUTION STATEMENT
Distribution limited to U. S. Government agencies only; this report documents test and evaluation; distribution limitation applied December 1972. Other requests for this document must be referred to the Air Force Armament Laboratory (DLDG), Eglin Air Force Base, Florida 32542.

11. SUPPLEMENTARY NOTES Available in DDC	12. SPONSORING MILITARY ACTIVITY Air Force Armament Laboratory Air Force Systems Command Eglin Air Force Base, Florida 32542

13. ABSTRACT

This was a research and development program on lined gun barrels directed toward selecting desirable barrel and liner material combinations which will increase the life of barrels in rapid fire gun systems and developing the fabrication processes for producing these barrels with a metallurgically bonded liner. Coextrusion was used as the method for producing the lined barrel stock. The program was divided into two parts with the first part directed toward producing lined .220 Swift barrels of selected material combinations for testing in the M-60 gun. The second part was directed toward producing a test quantity of 25mm barrels for testing in the GAU-7/A Gun System using the best material combinations and the fabrication techniques developed in the first part. Coextrusion was used as the method for producing the lined barrel stock. A-286 steel was selected as the barrel material, and TZM, Mo-0.5Ti, L605, Ta-10W, and T-222 were selected as the liner materials for the barrels. All the liners coextruded with the barrel steel satisfactorily over a small mandrel except T-222. The four successfully coextruded combinations were fabricated into .220 Swift barrels with swaging being used to rifle the barrels. The A-286 steel with a L605 liner was selected as the most promising combination for the 25mm barrels. The lined barrel blanks were produced by coextrusion on a 3850-ton press using a mandrel. The coextruded blanks were fabricated into GAU-7/A barrels by Philco-Ford Corporation using machining to produce the GAU-7/A gain twist rifling. Swage rifling over a mandrel cannot be adapted to produce gain twist rifling.

DD FORM 1 NOV 65 1473

UNCLASSIFIED

Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Lined gun barrels						
Rapid-fire weapons						
Coextrusion						
Swaging						
Rifling						
Machining						
Extrusion billets						
A-286 steel						
L605 steel						
Molybdenum alloy						
Tantalum alloys						